ELECTRIC MOVEMENT

IN

·AIR AND WATER·

WITH

Theoretical Inferences

BY

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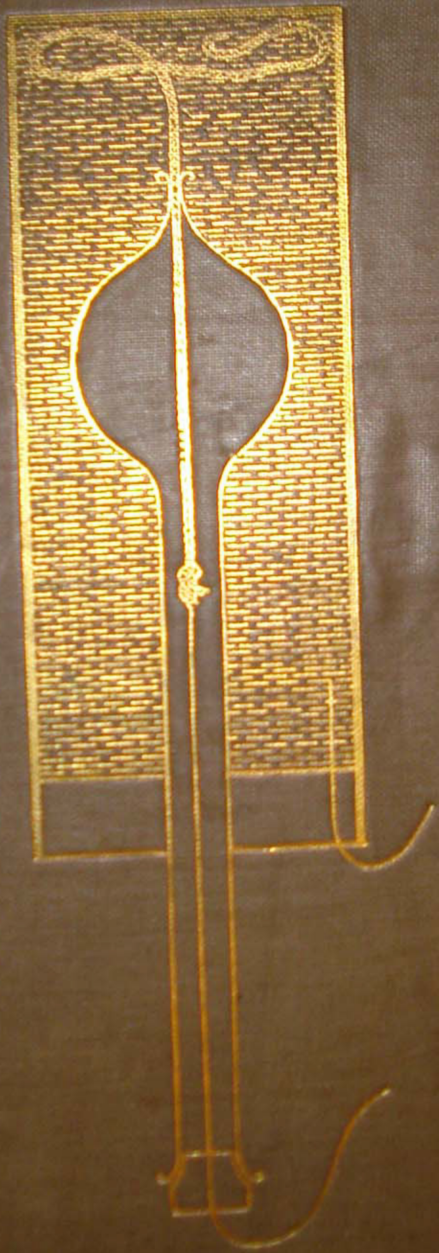

The Earl of Crawford
with the Author's compts

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PREFACE

MORE than half a century ago, when using my large hydro-electric machine, before it went to the Polytechnic Institution, I hit upon a remarkable experiment. Taking two wine glasses filled to the brim with chemically pure water, I connected them by a cotton thread, coiled up in the one glass, and having its shorter end dipped into the other. The two glasses were joined up to the machine, the one containing the coil of thread, by a negative wire, and the other, by a positive connection. On putting the machine into full action the coiled thread was rapidly drawn out of the negative vessel and deposited in the positive one, leaving for a few moments a rope of water about ·3 inch in length suspended between the lips of the two glasses. The experiment was made with the machine in the open air, and its highest power was required for producing the effect. Unfortunately that degree of power could never be attained when the machine was fixed under cover in London, and I therefore failed in my attempt to repeat the experiment when the machine was exhibited in the theatre of the Polytechnic Institution; but it was always my intention to follow up the subject as soon as I could provide myself with a sufficiently powerful apparatus and could find leisure to devote to its use. This, however, did not occur until very recent years, and until then the experiment remained dormant and unnoticed.

On recommencing my investigation I found that at my then advanced age I was no longer able to endure the exposure incident to outdoor experimenting, and was consequently led to use powerful induction coils in substitution of a steam generator; and although I have never succeeded in reproducing the desired effect in precisely the same form as in the original experiment, yet the same result in principle has been fully attained, and on more than one occasion has been publicly shown. The chief difference in the effect produced was, that with the new apparatus a much thicker cotton could be moved; but the attainable speed was greatly reduced.

After starting afresh my investigation widened. From movement in water I was led to movement in air. Photography came to my aid and eventually enabled me to compile the connected series of illustrations which are appended to the following monograph.

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THE experiment now pretty well known which shows the travel of a cotton thread from a vessel of water negatively electrified into another which is positively electrified presents strong evidence of two currents flowing simultaneously in opposite directions, the negative being inside of the positive. It is essential to the production of this effect that the water be chemically pure, or sufficiently so to render it a very imperfect conductor; and yet a certain degree of conduction is necessary, for when oil of turpentine is used the effect is merely one of violent commotion, affording no proof of interchanging currents.

When the experiment is made with a couple of wine-glasses, each nearly filled with pure water, and having a few filaments of lamp-cotton laid over the slightly separated edges and dipping into the water at each side, the cotton crawls slowly over from the negative into the positive glass, while the positive water travels in the opposite direction and accumulates in the negative glass. If the cotton be prevented from travelling, the water in the positive glass passes over in greater abundance, but it is very difficult under these conditions to prevent the passage of sparks between the glasses, and when this occurs nitric acid is formed in the adjacent air, and, being absorbed by the water, destroys its necessary purity. A much better apparatus, both for exhibiting and investigating the effects, is delineated in fig. 1, on the sheet of diagrams following the printed matter. It shows a glass bulb about 2½ inches in diameter, having a neck of about 8 inches long on the upper side, and a tapering nozzle on the lower side terminating in a short parallel passage of about ·05 inch in diameter. Through this passage a string of loose cotton fibre is passed, the thickness of which is somewhat less than the diameter of the

Diagram 1.

passage. The upper end of the string is hooked on to the platinum wire by which the current is conveyed into the bulb, or it may be undetached and have a knot at the top to prevent it sliding out. A tall glass vessel, which may be called 'the tank,' is filled nearly to the top with pure water, and into this the bulb is plunged, and allowed to fill up through the nozzle to the level of the water in the tank, the depth of immersion being such as to allow one-half the length of the neck to stand out of the water. A powerful induction-coil is then to be connected with this apparatus, the negative wire being inserted in the tank, and the positive conveyed into the bulb. When the positive current from the coil is directed into the bulb the cotton travels upwards and the water downwards, and in so doing the surface level in the neck of the bulb sinks below the level in the tank to an extent dependent on the power applied and its continuance. On the other hand, starting under the same conditions, but with reversed action of the coil, the cotton descends into the tank instead of rising out of it, and, being assisted by its weight, its descent is more rapid than its previous ascent. At the same time the water in the neck, instead of falling below the level in the tank, rises above it, so that the positive action operates in both cases against the resistance of an adverse head. If any further proof were needed of the co-existence of opposite currents, it is afforded by the fact that when a magnified figure of the process is projected on the screen of an electric lantern, the upward and downward flow of the water is conspicuously displayed by the appearance which always attends the entry of a heated current into a colder medium. But when the lantern is applied for this purpose the tank must be flat sided to prevent distortion of the image.

The nozzle should have a parallel passage at its extremity of about three diameters in length, but much less will do, though not so effectually. When the parallel passage is much longer, the water is apt to boil in passing, and then a stream of fire fills the channel and quickly destroys the cotton. In all the above experiments the induction-coil which was used was sufficiently powerful to give sparks eighteen inches in length, but a more frequent spark from the same coil of about three inches in length was found to be the most effective. Balls of equal size were used on each side of the air-gap so as to get equal sparks in both directions. I have however obtained similar effects with a coil of very inferior power by reducing the thickness of the cotton and the diameter of the passage to proportionately smaller dimensions.

In this first stage of the experiment the cork in the neck of the bulb is left loose to admit air, but in the next operation it is closed, the bulb and neck being first completely filled. The water is thus locked in by atmospheric pressure, so that there can be no outward passage without an equal inward passage taking place at the same time. Under these circumstances the water is seen, by its heated condition, still to come out, though no vacancy takes place in the bulb. The necessary inference therefore is that the positive water on issuing from the bulb changes its polarity and re-enters as a negative current, so that an equal circulation is established. But in the former case the quantity of water which was expelled from the bulb was greater than that which entered, whereas in the present case the quantities are equal, and as the expenditure of energy must in both cases be the same we have to account for the apparent deficiency of the work done by the negative current in the previous uncorked condition of the bulb. The explanation seems to lie in the fact that the negative current has to encounter more friction from the fibres of the cotton in passing by an inside route than the positive meets with in following an outside course, the result being that the negative current has more work to do in the production of heat. The fact that much heat is so generated by the negative current is unquestionable, for steam is seen under lantern examination to burst out in puffs from the meshes of the cotton.

Having thus described the details of the experiment in its various phases and the apparatus used in the operation, I shall now attempt a connected explanation of the effects produced.

The bulb when plunged into the tank is in the condition of a perforated Leyden jar, differing from an ordinary one in being coated with a slow conductor (pure water) instead of the usual tinfoil. The neck, or that portion of it which remains out of the water, corresponds with the uncoated part of the jar. The effect of perforation in a jar with metallic coating is instantaneous discharge through the hole in the glass, but in the case we are discussing the conduction over the surface and through the connecting channel is so slow that the bulb can be re-charged before neutralisation is completely effected. When we want to slow down the discharge of an ordinary Leyden jar we use a wet string as a discharging conductor. In the present case the water and cotton in the connecting channel act in the same capacity, but with greater effect owing to the purity of the water. In all cases the neutralisation has to be effected by cross currents through the conductor, and the question arises, How are these to pass without collision? Now, since it can be proved that positive electricity acts divergently, while negative acts convergently, it is natural that the negative should draw to the interior of the string and the positive to the exterior, and so avoid interference. The travel of the cotton is not an essential feature in the effect, but only an indication of the existence of a central current. The result is the same, so far as the interchange is concerned, whether the cotton is fixed or free, and even by reducing its length to a mere plug in the hole the travel of the water in contrary directions is equally effected. The method of conduction is therefore the same both in the case of the experiment and in the ordinary case of using wet string to retard the discharge. Nature is very economical of methods, though boundless in variety of application, and it may be questioned whether a mode of conduction established in a single instance may not in all cases be essentially the same.

As to the nature of the motion upon which the cross-movement of the water and cotton depends, I think a clue to the action may be found in the study of the Diagram 3. smoke-ring, of which the diagram, fig. 3, shows a cross-section, the direction of its motions being displayed by arrows. On the two outsides the arrows are pointing downwards, while on the two insides they are pointing upwards, and it is easy to see that an action of this kind operating in the dividing channel between the two vessels would tend to give upward movement to the cotton in the centre and a downward movement to the water on the outside. Upon this principle the cotton experiment in all its phases can be explained.

If Lord Kelvin's views on vortex atoms be true—and taken in connection with those of Helmholtz they have most weighty claims to acceptance—vortex motion must be the most universal of all motions, and it will be impossible to exclude it from the domain of electricity. In fact, a further consideration of the properties of the smoke-ring will show that they are quite of a nature to fall in with the dual character and the known facts of electricity. I have referred to its motion as viewed in transverse section, and its facial movements remain to be considered.

Diagrams 2, 4. These are of opposite natures; they are outward and divergent on one side, inward and convergent on the other side, as shown by the arrows in 2 and 4 on the diagram sheet. These conditions correspond with pressure and suction on opposite sides. In a crowd of electrified rings pressure sides would repel pressure sides and be attracted by suction sides, and these forces would operate to draw the rings into lineal adhesive arrangement well adapted by elasticity for vibratory transmission of energy. The repulsion of two suction sides could also be explained as a secondary action, caused by their pulling round two pressure sides to take their places. All effects would be reversed by change of polarity—that is to say, by turning the axis of rotation half-way round, or by a reversal of the magnetic circulation.

The rings would represent molecular movements which in point of size might vary from inconceivable minuteness to others of vastly larger dimensions formed by a congeries of smaller ones. The electrical analogies of smoke-rings are also strengthened by a comparison with magnets. We know that if a wire carrying a current be passed through a hole in a card sprinkled with iron dust, the particles resolve themselves into whirls around the wire. Conceive the wire to be bent round into a circle and joined at the extremities. The result would be a circulating current with transverse rotations similar ~~to~~ those of the smoke-ring, and in the absence of resistance the motions would go on for ever. A monad system of electric action constituted on up this principle would represent in an ethereal form the elementary conditions both of current and magnetic electricity. I will not venture to say that a magnet is constituted exactly on the same model, but it certainly possesses features of similitude to a lengthened smoke-ring. Two oval curves straightened on the inner sides would represent the transverse section of such a ring, and the single curves shown Diagram 5. in diagram, fig. 5, may be taken as the mean path of the so-called 'lines of force.' Conceive the central parallel space to be occupied by columns of 'Ampère whirls' breaking away in strings at one end and rejoining at the other, and we should then have a figure composed entirely of whirls and having an internal and external flow in opposite directions gradually declining into heat. Like a watch, a magnet is put into a state of tension by an outward application of force, and like a watch I conceive it to be gradually let down by a process of escapement. The severance at the issuing end would be the response to the impulse at the entering end, and this constant repetition of stopping and starting would constitute an escapement. The curvature of the lines would imply inertia, and their tensile condition would result from polarity, the energy being transmitted most probably by vibration. Ampère's theory of whirls is generally accepted, and those whirls may themselves be vortical, like the smoke-ring. I can conceive no other form of vortex that would account for the polarity. But I fear these speculations will be deemed both too daring and too vague. It will be more to the purpose to show experimentally that lines of force apparently magnetic can be generated on non-ferruginous dust by interrupted Illustrations Nos. 1, 2, 3. electric discharges in transverse direction. The illustrations numbered 1, 2, and 3, in the following series, all represent effects produced by a succession of spark discharges through a hole in a sheet of cardboard covered with a film of light dust, the hole in each case being represented by a black circular space in the centre. The sparks were derived from a powerful induction-coil with a half-gallon Leyden jar interposed on the circuit so as to reduce the length of the spark. By this means a spark naturally of 18 inches long was condensed to about 1-inch at the gap through the hole. In applying the dust to the plate a circular shield was used to keep it clear of the space within which the wind of the spark would disperse it, and, the sifting apparatus being cylindrical, the form of the dust-figure was annular to begin with. The material of the dust consisted of equal measures of calcined magnesia and purified lampblack in finest powder. A few discharges sufficed to throw the entire ring into circular No. 1. lines, as shown in No. 1. The form of the figure is

No. 3. greatly modified in No. 3 by setting up six short glass pillars at equal distances round the inner edge of the figure. In this case the dust-lines are seen to be rooted to the glass columns and stretched into arches between No. 4. them. A further modification is shown in No. 4, in which six wooden hemispheres touching one another are substituted for the separated glass pillars. It is impossible to look upon these figures without recognising the polarisation of the particles, but owing to the adhesiveness of the dust, their motions can only be imperfectly seen. This impediment, however, is removed by using finely powdered *hard* carbon and substituting a perforated glass plate for the sheet of cardboard. The particles of this dust move with great facility on glass, and, although the lines they form are less boldly developed, their motions can be distinctly seen when the figure is projected, in the course of formation, on the screen of the electric lantern. When the lines are thus viewed, they are found to be in rapid rolling motion, but with very little outward progression, and they also show a quivering longitudinal motion. A very significant feature is elicited by making at the outset a break in the continuity of the ring, as

No. 2. shown in No. 2. In this condition the ring becomes
analogous to a horse-shoe magnet, and it behaves in the
same manner. The particles of dust are jerked out on
both sides, and form up into short threads, which roll
themselves towards the narrowest part of the gap, and
there place themselves in end-to-end connection with the
No. 5. interrupted lines. No. 5 shows a magnified view of the
gap when the filling-up process is about half completed.
It may be said that the polarisation under which these
effects are produced is only electro-static, but at all events
it presents sufficient parallelism with true magnetic polarisation to indicate a close relationship between the two.
We may assume that the dust movement is only a
cumbrous imitation of an incomparably more subtle and
agile movement of air molecules, which would instantly
close up the gap in the circle, but would require a
lengthened continuance of the action to drag up the
ponderous dust particles into line. But the sluggish
motion of the dust, both as regards rolling and longitudinal progression, may fairly be taken as indicative of
corresponding swifter movements on the part of the
air molecules. I must leave it to others to draw a

distinction between lines of force produced electrically and magnetically. I have done my part in showing the apparent resemblance.

Although the arc-lamp lies rather outside of my subject, it appears to me to be so analogous in its action to the water and cotton experiments, and so confirmatory of vortex action, as to justify a reference to it. The heat and light developed in arc illumination are generally regarded as mainly attributable to the superior efficiency of the positive current; but how are we to reconcile this opinion with the fact that the positive action is one of expansion, and therefore tending to reduce heat instead of intensifying it? And how are we to explain the formation of the crater? Particles shot off from the positive carbon would not issue preferentially from its centre, but from its edges, which would be the first to yield to erosion. On the other hand, condensation and impact are fertile sources of heat; and if we admit the existence of a returning central current focussed upon the centre of the positive carbon, we not only explain the chief source of the heat and light, but also the scooping-out of the crater. The form assumed by the negative carbon is quite in harmony with this view. The lines of force are thrown out dispersively from the positive electrode, and, being attracted by the negative, they sweep round and erode it into a tapered form with a knob at the end. The polarity is reversed by change of front, and the lines flow back on an inward course under the joint influence of both electrodes and impinge upon the positive centre, thereby forming a crater and intensifying both heat and light by secondary action. The process involves a figure approximately represented by fig. 6 (diagram sheet), which closely resembles the section of a smoke-ring, and agrees with the cotton experiment in showing outside and inside movement in opposite directions. Whether any part of the impinging energy re-enters the positive carbon in aid of the continued emission, or whether it is entirely expended in the production of heat and light, is a subordinate question. If all the lines re-enter the carbon, the figure would be that of a continuous smoke-ring. Otherwise it would be a figure of the same order, but discontinuous. It has recently been shown that the crater is flattened, and the lower carbon is more deeply indented, when the light is enclosed and the admission

Diagram 6.

of air restricted. But this only implies that the impact is in some way rendered less oblique on the lower carbon and more diffused on the upper. The character of the figure remains the same.

In all the experiments I have hitherto described an induction coil was used as the source of the power, but the whole series of figures which I am about to bring forward were produced by a powerful Whimshurst machine, which is capable of far more general application than the induction coil. It has sixteen plates of nearly 3 feet in diameter, and is driven by an electro-motor. It is furnished with condensers of different sizes, varying from pint bottles to ten-gallon jars. I am indebted to Mr. Whimshurst for personally superintending its construction, and it has proved an indispensable instrument in my experiments. In using it, my practice is to shunt the spark on to a branch line when the object is to exhibit on the main line the tensional effects which precede or attend the spark. When the spark itself has to be depicted along with its accompaniments, the object is accomplished by widening the air gap on the shunt line, so as to make it more resistant than that on the main line.

Wimshurst

The kind of dust which is most generally applicable for dust delineation is Tripoli powder; but where extreme mobility is required, calcined magnesia mixed with carbon in the form of purified lampblack is preferable. Lycopodium dust is still more sensitive, but is very apt to take fire. The dust in all cases must be sifted upon the plate by a mechanical jogging apparatus working vertically in guides and shaking out the dust by striking gently against stops. The figures are generally improved by a minute application on the glass of solution of wax in benzole, which must be rubbed off with the hand until the plate is perfectly dry and free from obscurity.

I will now exhibit the dust figures which more especially bear upon the points I have already discussed, and shall leave others to be introduced at a later stage of this paper.

Illustration No. 6.

No. 6 illustration is a dust figure produced by that form of electric discharge usually called brush action, and which, in this particular case, was only of momentary duration. Here at once we see an example of inside and outside action analogous to the corresponding action in the water and cotton experiment. The outside sweep of the positive is indicated by the denudation of the dust, while the inside negative current is marked by a central stream of dust directed towards the positive electrode. It is difficult to catch the proper moment for stopping the action, which, if continued too long, disperses the dust altogether, or, if too short, prevents the completion of the return passage.

No. 7. No. 7 is another example of the same kind, but in which the inside dust stream is carried home to its destination by a somewhat longer continuance of the brush action.

No. 8. No. 8 is also a brush figure in dust, but in this case a small spark has been allowed to pass between the two electrodes. Here the displaced dust is carried vigorously backward, not only on the central course, but in rear of the electrode, where the spark is inoperative. The path of the spark is seen in the centre of the figure, and the exterior shows a multitude of brush lines diverging from the positive electrode and then converging under negative influence upon the spark line. The spark itself has no carrying power, and the dust is swept back exclusively on the brush lines. This is especially apparent at the back of the electrode, where the spark can have no effect. The limit to which the dust has reached by expulsion is there clearly seen, and its return may be traced back to the edge of the electrode, where it appears like a circular corona.

No. 9. No. 9 shows the effect of intercepting the brush lines by an interposing dust plate. The lines in this case are projected vertically downwards from a positive electrode above the plate towards a negative electrode below it. The result shows a multiplicity of impacts like large and small raindrops. Every impact exhibits an outside radiating ring with a dark spot of dust in the centre. A transverse section of the figure, already shown in No. 6, would exhibit the same conditions of a white outside and a dark inside. By reversing the current and
No. 10. using a fresh dust plate we get a picture (No. 10) of the negative action, showing fewer and larger impacts than are seen in No. 9. In this case the inward direction of the force is manifested by a general shrinkage of the field of dust towards each point of impact. When viewed with a suitable side light on the actual dust plate the formation can be distinctly seen as in a model,

showing at each impact a hill, a crater, and a cone like an extinct volcano. The impact of a smoke-ring if sufficiently strong, would produce corresponding effects. The dispersive side of the ring would harmonise with the radiating positive impacts, while the convergent side would accord with the appearance of the negative action. In both cases the central lodgment of dust seems to imply a vortex core, and other appearances testify to inward and outward radiations.

No. 11. No. 11 is a highly enlarged figure of part of No. 7, and shows that the brush lines in coursing along the plate make a succession of minute impacts, each showing a black spot of dust with a positive clearance around it. In exceptional instances the spot is absent, but the majority of cases in which it is present is so great that it is fair to presume that where not present it has been knocked aside by the crowded rush of other lines. I am quite at a loss to understand what these spots can represent if they be not vortex centres, in which case we must regard the whole figure as composed of strings of cored vortices linked together by polarity, and transmitting energy by some process of conduction.

I now come to another mode of illustration, in which a photographic plate is substituted for a dust plate, and in which the luminosity of the discharge produces its own picture when taken in a perfectly darkened room.

I shall begin with a representation of a beautiful No. 12. luminous star (No. 12), produced by a single powerful discharge delivered from the pair of 10-gallon condenser jars of my Whimshurst machine. The discharge is positive, and is taken from a metallic disc resting on an insulated photographic plate. It shows a tensional figure distinct from spark discharge. It is, in fact, the product of the tension which results from or accompanies a spark taken on a shunt line. The figure as printed is on a scale of fully twice natural size in lineal measurement, and it is whiter in the print than it was in reality, but in form and character it is identical with the original. The discharge, although incidental to a spark, is in itself unipolar in the sense of having no metallic pole of opposite sign associated with it. The radiations of the figure are of course molecular, conveying energy by handing it on from molecule to molecule, or from cluster to cluster of molecules, with comparatively little translative movement.

The energy wastes as the figure expands; but before exhaustion is effected, a change of polarity takes place, which brings back the remnant on the same lines to the point of issue. It is, perhaps, the simplest form of sparkless discharge that can be obtained, and it is desirable to trace it to its origin and investigate its action. The figure is undoubtedly molecular, and the medium is atmospheric air, and therefore gaseous. Without molecules in a state of mobility the figure could have no existence, neither could it be produced without imparted motion from without. The question now arises, What is the nature and origin of this imparted motion? Its genesis in this case clearly lies in the mechanical power applied to the Whimshurst machine, which by a process of induction and adhesion draws upon the inherent electricity of one set of molecules and transfers the product to another set, thereby creating unequal conditions of charge, which strive to readjust themselves and restore equilibrium.

Faraday maintained that molecules must be largely stored with electricity, and these stores present the most obvious sources of supply. It is probable, therefore, that free electricity may be correctly defined as detached molecular electricity. 'Positive' and 'negative' are appropriate terms for difference of quantity and potential, but it is confusing to apply them to dual nature as well. 'Inward' and 'outward' electricity would better meet my views, but I cannot presume to introduce a new nomenclature. The great mobility of air molecules and the amplitude of their movements render their electrical action much more discernible than in other conditions of matter; and I trust that the pictorial representations upon which I am now entering, stamped as they are with the truth and accuracy which is characteristic of photography, will facilitate the labours of other investigators in their endeavours to unravel the intricacies of electrical action.

The luminous star figure already introduced may at first sight be regarded as inconsistent with the principle of circuit, but we must bear in mind that what we see is molecular action produced by an agent which we don't see and very imperfectly understand. The electrical *effects* are alone cognisable, and these must conform to the laws of inertia, friction, and heat production, whether the fundamental agency does so or not. Recoil always follows an outburst of electric energy, and causes a reflux to the electrode from which it issues. There is always resistance to the passage of electricity from air into metal, though apparently none, or comparatively little, in the reverse passage from metal into air; so that a metallic electrode acts in a measure as a valve closing against return. Judging from less ambiguous figures to be hereafter shown, I am able to say that the halo around the electrode is in this figure the result of checked re-entry, but great developments of this recoil action will be seen as we proceed.

No. 13. No. 13 is an enlargement of part of the last figure, and is chiefly designed to show the remarkable manner in which the lines that make the most headway receive contributions from other lines which are unable to compete with them. The tendency appears to be to consolidate into a smaller number of main lines, which will afford better conduction than a large number of smaller ones collectively of the same area. The junction is not effected by lateral fusion, but by pointed penetration, each puncture being marked by a speck of light seemingly attributable to an attendant production of heat. More of this kind of action will presently be shown.

No. 15. No. 15 shows the widely different figure produced by reversing the current, all other conditions being the same, except that the electrode is reduced to a point to give more emphasis to a figure which requires every advantage to make it sufficiently distinct for critical examination. The diminutive size of this negative figure, in comparison with the positive one, is the first thing to be noticed; and it may be asked, How can this be reconciled with the assumption that negative and positive action are equal? The answer is obvious if we admit that the negative represents suction and the positive pressure, because in that case the negative flow will be resisted by condensation, while the positive will be helped by expansion. The negative therefore has more unseen work to do in the production of heat, and its action is only rendered apparent by nebulous light around the electrode. The negative figure as it appears in the illustration is enlarged in much the same proportion as the positive star figure (No. 12), and the incoming nebulous streams, growing denser as they advance, are very distinctly seen. The recoil action is also clearly manifested by the protrusion of antler-shaped emanations,

which are obviously of the same nature as the ramifying dispersive lines thrown out in the positive star figure; and it is important to observe how these reactionary horns cling to the negative streams, and overlap them without combining with them. This peculiarity is more distinctly
No. 16. shown in an enlarged figure (No. 16), which is taken from another experimental figure of the same kind, but more suitable for enlargement. In this example the positive horns almost encase the negative streams, and distinct proof is thus afforded of inside and outside motion in opposite directions without interference or intermixture. I abstain, at present, from commenting upon the detached figures on the outskirts of No. 15, as I shall have more to show and to say on that head further on.

Up to this point the positive and negative electrodes have been kept so widely apart as to show no sensible effect on each other; but in the next figure
No. 17. (No. 17) the opposite electrodes are brought near enough to exhibit mutual influence, though not sufficiently near for spark discharge. In this case the radiations from the rear and sides of the positive electrode present much

the same appearance as before; but those facing the negative electrode are drawn towards it, and for the most part consolidate into thicker lines by that curious process of confluence which has already been described, and which is more definitely seen in the enlarged picture No. 14. of part of the present figure, as displayed in No. 14.

The central passage being the shortest, the potential is more lowered there by the negative suction than elsewhere, and the outlying lines are consequently drawn inwards and caused to deliver their energy into channels more competent, to reach the negative electrode. The needs of the negative are only partially satisfied by the supply from the positive, for it is apparent that the negative electrode continues to draw electricity from the air in the same manner and nearly to the same extent as in its previous unipolar capacity. It does however present some new features, especially the projection of positive lines by secondary action to catch up lagging patches of negative cloud advancing to the same destination.

A very interesting variety of No. 17 is shown in No. 18. No. 18, which is produced by pointed electrodes raised half an inch above the surface of the photographic plate. In this case we have the curious phenomena of black tips at the terminals of nearly all those lines which fail to reach the negative goal. The dark tips seem to mark the turning-back of the ineffective lines and the reversal of chemical action due to change of polarity. Minute figures in flight from the positive region will also be seen, together with a great display of negative light thrown back to the positive end.

In all these luminous figures induction has been as much as possible excluded, and I have now to show the amazing developments which display themselves under different degrees of induction applied beneath the plate on which each figure is taken. Induction is always strongest when thus brought to bear on the reverse side of an efficient dielectric, but would only reach a maximum by an infinite reduction in the thickness of the dividing impenetrable barrier. In that case, action and reaction would become equal, and in the absence of resistance would go on eternally.

The intensified effect of strong induction is rendered emphatically apparent by comparing the star figure in

No. 12, in which induction was almost nullified, with the No. 19. magnificent figure in No. 19, where the two electrodes were only separated from each other by a double thickness of ordinary sheet glass. The difference in the size of the two prints, 12 and 19, does not adequately represent the difference of size between the actual figures, for the print is on a scale of 2 to 1 in the case of the star, while it is of natural size in that of the induction figure. To make them proportionate, would require the print of the latter to be 30 inches in diameter; and yet it required a less powerful discharge for its production than the other. It will be seen also how minute, incisive, and symmetrical are the lines of diffusion as compared with the lines of the unipolar figure.

No. 20. A companion negative figure, shown in No. 20, was produced by the same discharge by using two photographic plates placed back to back, with the film surfaces outside. The opposite electrodes were in coincident position and in contact with the glass, but, as I shall have to revert to both these figures at a later stage, I shall not at present dwell further upon them.

I shall next proceed to illustrate other interesting effects obtained with minor degrees of induction and by varying the mode of application.

Referring back to the unipolar negative figure in No. 15, it will be observed that the negative manifestation is purely of a nebulous character, indicative of the production of heat, and that the lineal configuration is limited to the reverse action of recoil, which, of course, is positive. A very small amount of induction is, however, sufficient to bring lineal action more into play. This effect of induction is beautifully shown in two illustrations of much the same description (Nos. 21, 22). Nos. 21, 22. In these figures lineal streams are seen flowing convergently towards separate centres, where they collide and are shattered into heat clouds, thus representing the conversion of electric energy into heat energy; the one consisting of organised movement, and the other of promiscuous vibrations. A further examination of these figures will show that the three heat clouds in each figure remain sufficiently electrified to carry on the action to the metallic pole, though with very reduced energy, as is shown by the comparatively feeble development of heat which is there indicated. It will also be observed that the protrusion of reactionary horns from the negative centres has ceased, and that, in lieu thereof, bristling spikes are thrown out from various parts of the converging lines. In previous figures where induction was practically excluded small detached cloud spots of negative electrification were seen to be floating inwards, but these showed no organisation. Similar detached spots may be seen in connection with the present figures, but these are in organised form, having their own converging lines and collision clouds.

With stronger induction the converging lines and their tributaries become very pronounced, and indicate the initial gathering from the air with wonderful precision and symmetry. No. 23 shows a magnified portion of one of these figures. The branches bear a remarkable resemblance to feathers, the barbs of which represent gathering feeders advancing in close array from opposite sides and colliding on the dividing lines, which are thereby raised to the temperature of ignition, and become ducts for transmitting the energy to the negative centre. No. 23.

I will now pass on to double figures produced without spark between two electrodes, but differing from those already shown in being modified by underlying induction.

No. 24. No. 24 shows the remarkable effect of a mere thread-like strip of tinfoil stuck upon the under-side of the photographic plate so as to establish a subjacent axial line of conduction from centre to centre of the two electrodes, the strip itself being insulated. By this means we obtain alternating induction beneath the plate, thereby favouring oscillation and the production of secondary figures within the primary areas. In the present case the brilliant figure within the positive area must be regarded as a reactionary negative figure bearing a great resemblance to the negative primary, though showing much greater detail. On the negative side there is also a sub-luminous fringe, increasing in luminosity towards the centre, where a well-defined line of light, which has its correspondent within the positive area, marks the inception of spark-discharge which is about to take place, but is defeated by its occurrence on the shunt line.[1] The two figures are drawn out towards each other, and actually touch, though not sufficiently to pass the spark. The curvature of the lines on the negative side shows their convergent flow from the adjacent air, while positive dispersion is shown with equal clearness by the faint outside lines in the opposite division. On both sides we have unmistakable evidence of the production of heat and consequent light by convergency.

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[1] It is difficult to say whether the sparkless discharge is due to a preliminary state of tension leading up to a spark, or to self-induction succeeding the spark. In either case the spark on the main line is defeated by its occurrence on the shunt line.

No. 25. No. 25 is an enlargement of the central luminous figure on the positive side of the preceding picture. Or, to be more correct, it is taken from a similar figure produced in exactly the same manner, but which has more strongly defined lines, and is therefore better adapted for illustration. From this enlarged figure it will be distinctly seen that the reactionary inward flow has taken place on the positive lines of emission, and it seems probable that the dulness of the exterior portion of those lines represents the transitional stage of reversing polarity. The enlargement also shows a profusion of double-headed junction lines, which seem to indicate a quivering variation of potential due to minor oscillations.

No. 26. No. 26 is the same as No. 24, except that it is made in six jumps instead of only one, the intervening space being equally divided by equidistant circular spots of tinfoil; and, by way of comparison, a figure of four sections No. 27. (No. 27), produced without subjacent induction, is exhibited to show how much the definition is dependent upon the function of the strip of tinfoil beneath the plate.

No. 28. In the next illustration (No. 28) the strip of tinfoil beneath the plate is discarded, and a separate earth connection is given to the underlying electrode of each figure. In this case the two luminous figures, which are of great beauty, and much more unlike each other than is usual, are circular in form, and are in no degree drawn out towards each other. They are also quite out of sparking range, but are in communication with each other by a system of fine lines, like cotton fibres. The pair of figures are like the two sides of a Leyden jar under process of discharge by leakage. The connecting lines are seemingly all of the positive brush description, and are doubtless acting as positive ducts; but where are the negative ducts, if they be not inside of the positive ones, as they undoubtedly are in the case of the water and cotton experiment?

Some very curious effects are produced at the junction of the connecting lines with the fronds of the negative figure, but they are too minute to be distinctly seen by unassisted vision. I select for enlargement one small patch not materially different from many others. It is No. 29. shown in a highly magnified form in No. 29. The consolidation of the minute communicating lines before joining the negative is here distinctly seen, and their discharge upon the head of a negative frond produces a strong development of light, together with a recoil from the negative which has all the appearance of a splash followed by an issue of minute positive antlers. To the left of the splash a number of negative fronds may be seen with positive lines coursing over them, and detached portions of negative heat cloud may be observed with positive lines thrown out to catch them.

The brilliant portion of the figure on the positive side appears to be only a further development of the secondary action, which in the whole of the preceding series of analogous figures has been gradually enlarging, until in the present case its boundary extends nearly to the limit of the initial positive action. Still, however, there remains an outskirt of primary radiation which displays the singular phenomenon of a multitude of small detached figures each flying away with a speck of light at the rear. Similar detached figures, more distinct and more isolated, may have been noticed in previous illustrations, and it is now time to discuss them. They are undoubtedly fractured positive lines, such as can be easily produced by diagonal impact. No. 30. Thus, in No. 30 a cluster of strong brush lines is delivered obliquely upon a photographic plate by a single powerful discharge from a positive electrode raised ·8 inch above the plate. The lines are broken by the impact into pieces of various sizes, some of them as small, and most of them many times as large, as those skirting the previous figure; but all are of one kind. In this, as in all other cases, whether electric or magnetic, it seems impracticable to vary the type of figure by subdivision, and it would be deeply interesting to know how far, theoretically speaking, diminution could be continued without involving radical change. In these fractured figures the dispersive part is unquestionably positive, and the bright spots may be assumed to be negative, partly because they coincide with the black dust spots in Nos. 9 and 10, and partly because they visibly attract the tips of the positive lines following closely behind them. The tips in the present figure are seen to bend inwards towards the spots, and actually strike into them, thereby proving opposite states of electricity,[1] and strongly confirming the double composition of electric conducting lines. The effect may perhaps be attributed to self-induction consequent upon interruption, but the evidence of dual composition would remain unaffected. The discharge in this figure was taken from the 10-gallon condensers of my Whimshurst machine, but fractured lines can be produced with far less power, though not so incisively.

It is very difficult to obtain distinct results by a similar treatment of negative lines, because the negative action is more sluggish than the positive, and also because they produce much more fogging effect upon the plate; but in one case, and only in one, I have succeeded in obtaining a good example, which, in a magnified form, is exhibited in No. 31. It represents the impact of negative lines emanating from a negative electrode raised about ·8 inch above a photographic plate, and receiving a sparkless discharge from a positive electrode raised 1 inch above the plate. The electrodes were about 8 inches apart, and the plate was insulated. The discharge was delivered from the 10-gallon condenser jars, and was very powerful. The figure produced under these conditions exemplifies in a most remarkable manner both primary and secondary actions, and the pronounced tendency of the positive streams to embrace the negative emanations is conspicuously shown.

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[1] Since writing the above I have obtained additional evidence upon this point. Flour sulphur is attracted when lightly dusted over a surface positively electrified, and repelled when the electrification is negative. By applying this test, which was suggested to me by Mr. J. W. Swan, I found that the relative electrification of the streamers and spots agreed with the views expressed in the text. Lichtenberg observed not only that sulphur adhered to a positive surface, but that red lead acted in the same manner towards a negative surface. Furthermore that when the two powders were rubbed together and applied as a mixture, they tended to separate and settle in the above discriminating order. Although I have not yet succeeded to my full satisfaction in the application of these tests, I have obtained sufficiently distinct results to prove the correctness of my previous conclusions. Bare glass of a proper sort, as well as resinous plates, may be used, but great precautions are necessary to avoid ambiguous effects where the electrifications are feeble.

No. 31.

Another equally curious case of a different kind is presented in the pair of figures in Nos. 32, 33. In this case two photographic plates placed back to back were used with the films on the outside. The upper side of the double plate carried a metallic ring, about 4 inches in diameter, which served as a positive

Nos. 32, 33.

electrode, while the end of a negative wire was brought into contact with the lower side of the double plate at a point coincident with the centre of the ring. When a discharge is made under these conditions, a very feeble emission of positive horns takes place outwardly from the ring, but thick radiations are thrown off from the inner margin, and expand in volume as they approach the centre. The recoil action is very conspicuously shown by a bright circle of light at the inner edge of the ring, where the return is checked by the sort of valve-action already mentioned. The same white junction spots which so generally accompany positive emanations are profusely displayed in the figure; and yet it is so different in general character from all previous examples of positive action that it is difficult to regard it as essentially the same.

Turning now to the obverse side of the double plate, we find a negative figure displaying equally unexpected features. It shows detached figures of various sizes, all distinctly defined as independent systems, and many semi-detached ones of perfect symmetry, all exhibiting the usual collision clouds at the confluence of converging lines, and finally evolving an intense nebulous light at the common centre. No stag-horn reactions are visible, but the tips of the feathery plumes show exceptional markings, like ears of corn, which may perhaps represent reactionary effect, or may be related to the black tips shown in other figures.

All the preceding luminous figures were produced by single instantaneous discharges. Continuous discharge of the brush character gives very bad luminous definition, for the lines are so fine and so multitudinous that they
No. 34. run together, and show only a haze of light. No. 34 is an example of a figure thus produced by continuous discharge. It shows streamers issuing from the front, back, and sides of the positive electrode, and after becoming invisible reappearing by condensation, not only at the point of the negative electrode, but also around it. The condensation into sparks in front of the negative is very clearly shown, but they are very feeble, and not sufficiently luminous to blur the plate. It will be seen that they die out before reaching the positive terminal, being apparently absorbed in the positive haze. But the chief interest of this figure lies in its exhibiting the curious phenomenon of a black spark, which in this

instance divides into two branches, and may be traced nearly the whole distance between the electrodes. In its centre an extremely fine line of white light may be seen, but this is very minute in comparison with the adjacent blackness. Black lightning is a known fact of rare occurrence, and is generally attributed to excessive brilliancy deadening the eye to the perception of light; but that explanation cannot apply to the black spark in this experiment, where the light was barely sufficient for photographic definition.

I must now recur to the two large and fully developed electric figures in Nos. 19 and 20, which as yet have only been imperfectly discussed. As already stated, the two figures were simultaneously produced by the employment of two photographic plates placed back to back to each other and having coinciding electrodes of opposite sign on the outside faces. The two pictures produced under these conditions approximate to each other in appearance much more nearly than in any preceding figures of the same kind; and such being the case, it is probable that if much thinner glass could be used for the dividing dielectric, the difference between the two figures would almost disappear. The increase of similitude on the side of the negative consists firstly in the fading prominence of those broad soft luminous fronds which I have treated as inflowing streams derived from the surrounding air; and, secondly, in the increased protrusion all over the figure of reactionary spurs of a positive aspect. On the other side we have more finely divided lines coinciding in direction with the broader lines of the same character in the negative figure, but differing only in their greater subdivision, and we have a vast number of positive spurs closely corresponding with those on the negative figure. All this tends to show that both figures are negative, the one by primary and the other by secondary action. As there is no overreaching fringe of primary action to be seen in this case on the positive side, the presumption is that the secondary figure has completely obliterated the primary one. Although there is little or no difference in the size of the two figures, there is much more minuteness of detail and sharpness of definition on the positive side than on the negative. This apparent superiority of energy in the positive figure has been observable throughout. It was greatest where the induction was weakest, and is least where the induction is strongest. If I may venture upon a hypothetical explanation, I should say that regarding the electric generator as a pump which must fill before it can force, the negative stroke, representing suction, must take the lead of the positive, and will have to draw from a neutral atmosphere. In so doing it will create a deficit in the environment which will aid inductively the expulsive energy of the positive. Being first in primary, the negative would also be first in secondary action, and would thereby operate to reverse the condition of the environment, thus adding its own energy to the *recoil* energy of the positive, thereby producing heat and light by an invigorated convergency followed by a second positive outburst manifested by a multitude of minute "horns" over the whole area.

Whatever theory may be applied in explanation of these two remarkable figures, they are at all events the result of molecular motion actuated by electricity. The amount of symmetrical detail they exhibit is enormous, yet the time required for their production is only an immeasurably small fraction of a second. But it is to photography that we owe the power of recording such wonderful displays of electric activity. Photography, however, is not available for this purpose in cases where the light evolved is very strong. A bright spark fogs the plate and destroys all delineations, and it is only by its action on dust that I have been able to obtain even a rude picture of spark structure when resulting from a strong discharge. The spark has little or no longitudinal carrying power, but its lateral force is considerable. The only way to attain any success with dust delineation of a strong spark is to wax the plate and rub off the wax until only the smallest vestige of it is left. When a powerful spark is passed over a plate thus prepared and surfaced with a film of the finest possible dust, all the coarser particles are blown away in confusion, but a fine residue is left which clings tenaciously to the plate, and sometimes, though not always, will take the impression of definite incisive markings of the spark action. No. 35 shows a magnified figure thus produced. The spark was about 4 inches long, and was taken from the pair of 10-gallon condensers of my Whimshurst machine. The adjacent

No. 35.

dust shows negative action on the left division of the figure, and it would certainly have shown positive action on the right if the dust had not been too much disordered by dispersive force. The track of the spark is very distinctly shown, and it will be seen that it is flanked on each side by a line of spike-shaped radiations normal to the curvature of the track. These consist of black pointed forms separated by white streaks of denudation. Judging from what I have seen in other cases, I should interpret these alternations as indicating a series of oscillations between positive and negative, due to reversals of polarity effected with inconceivable velocity along the whole line. We may presume that these vibratory lines are exhibited on the plate in a sectional form, which implies that their actual form in free air would be that of rings with a core. This brings me again to the idea of the smoke-ring, though the sharp-edged form of the exterior does not agree with the outward curvature of that vortex form. But if the motions of the smoke-ring could be intensified up to lightning-pitch, I am inclined to think that their configuration would correspond with that of the spikes in the figure. At all events, there is every appearance of a core with an innermost centre, marked by a thread-like line of undisplaced dust.

In the production of the spark figure just described no underlying induction was used; but in the next No. 36. illustration (No. 36) an extremely narrow strip of tinfoil was affixed to the underside of the dust plate, on a line extending from centre to centre of the two circular electrodes, resting on the film of dust. A condenser spark was allowed to pass, and the result shows its track, together with two well-defined figures indicating four oscillations and very distinct contrasts between positive and negative markings. But here again we see clear evidence of a superiority of force on the positive side, which I have endeavoured to explain by assigning the initiative action to the negative.

I now pass on to a somewhat magnified picture No. 37. (No. 37) of a similar figure, in which the tension was sufficiently kept down to avoid violent discharge. In this case, owing to the lower tension, only two recoils are apparent, but the constitution of the spark is much more clearly shown than in the last figure. I must here observe that a spark taken over a surface under the influence of induction beneath is incomparably quieter than when such induction is absent. In the present figure it will be seen that the positive lines, due to secondary action within the negative area, issue from the spark track in hollow curves. On the other hand, the more abundant negative lines, caused by reaction within the positive area, curve in a similar manner into the opposite division of the spark track. The gradient of potential must therefore be from outside to inside in both cases, while the spark tracks themselves must be of opposite sign in relation to each other—the track being positive inside of the negative area, and negative inside of the positive. In confirmation of this view, we see the tendency of the positive lines at the junction to mount upon the outside of the negative; and we may infer that if the process were carried to completion, it would be effected by the one telescoping over the other. Many detached figures are thrown off from the positive fringe, all of which show the usual black centre, indicative of inward action, while their radiating exteriors bear witness to the opposite condition of dispersion. Altogether, the figure is full of information, and is a beautiful example of dust illustration.[1]

A very interesting, and I may even say surprising, No. 38. effect is shown in the next illustration (No. 38), in which negative streams (not sparks) were projected from an annular electrode upon a dust plate with a positive metallic ring beneath. The result is a circle of independent figures, each complete in itself, and showing such perfect compressibility as to admit of being crushed into the forms which are the most favourable for close packing. Each figure, though wedged against its neighbour, resists amalgamation, and there is no indication of their being mutually subject to either attraction or repulsion. Every figure shows a nucleus with a dark surrounding, penetrated by radiating lines running into an exterior nearly denuded of dust; and in all cases there is a boundary line between adjacent figures which seems to resist intermixture as if it were an integument. Their general appearance is strikingly like pictures of physiological cells; and, what is more strange, we see them in every stage of fission, from small beginnings to complete separation, and in every case the divided form displays the same internal structure as the original from which it springs. I have already spoken of electricity as organised motion, and we have here an example of it carried apparently to the very verge of life.

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[1] Since the above was written, I have distinctly ascertained, by the tests referred to in the footnote at page 38, that the spark track in the negative division of this figure is positive, while that in the positive division is negative. Also that the effects of the same discharge are reversed on the opposite sides of the glass.

But the above is not the only case of electric
delineation on dust presenting the appearance of organic
forms. The common lichen, which grows so freely in
pure air on sandstone rocks, is closely imitated in
No. 39. No. 39, which is another negative figure on dust; and
No. 40. in the succeeding figure (No. 40) we see arborescent
forms, showing trees and undergrowth, in which stems,
branches, and leaves find their approximate representa-
tives. Lastly, in the one remaining figure to be shown
No. 41. (No. 41), even the root is indicated lying at the foot
of the stem.

This final figure is worthy of a little further description. It is surrounded by patches of swept-up dust, derived from denuded margins, thus indicating negative electrification. From the interior of nearly

Fig 1

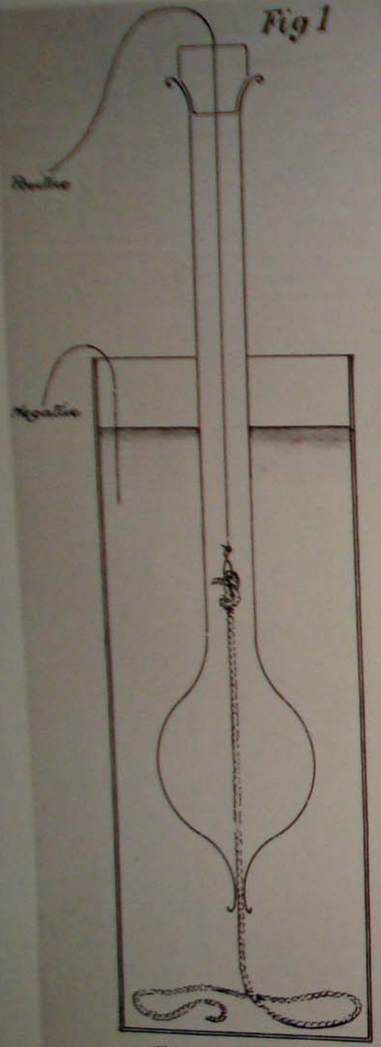
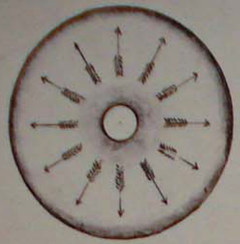


Figure 1 half size.

Fig 2



Positive

Fig 3

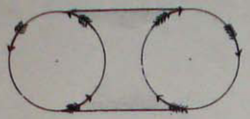
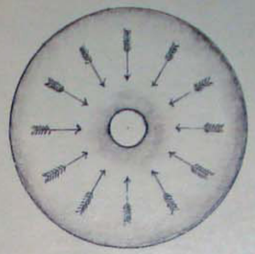


Fig 4



Negative

Fig 5

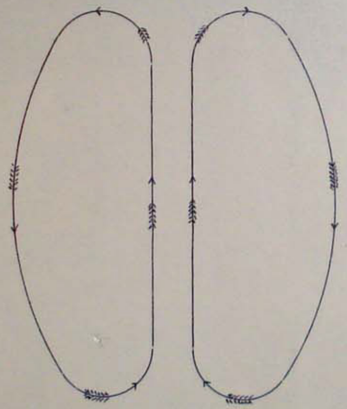
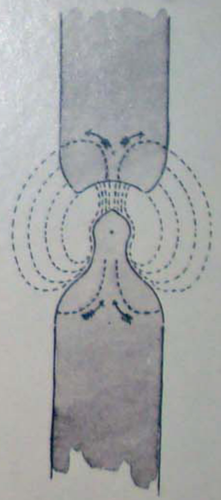


Fig 6



Diagrams

every patch we see the origination of a conducting line, which on its inward course unites with others, which in like manner go on combining, until one main trunk is formed leading to the base. From this point there is a rebound in positive form, which flows outwards along the same tracks, and its dispersive force breaks out in the production of highly divided vegetative forms.

We now come to the important consideration as to how far do all these experiments advance our knowledge of electricity. Many things have been illustrated, and I may hope they have in most cases been more or less elucidated.

Let me briefly recapitulate the particulars, in order to bring them more into one view:—

(1) An intelligible explanation of the water and cotton experiment has been offered, and its teaching indicated.

(2) The duality of electricity, apart from quantitative distinction, has been shown to consist largely, if not wholly, in difference of direction, the motion being in the one case outward and forward, and in the other inward and backward, as in the smoke-ring.

(3) The consolidation of brush lines into main channels of conduction, and the mode in which they coalesce have been clearly illustrated.

(4) Pictorial illustrations have been exhibited showing electric configuration in various phases; and the persistency of pattern, independent of magnitude, has been exemplified.

(5) The double composition of conducting lines has been displayed by fracture.

(6) Novel effects due to oscillation and secondary action, as well as to modifications of induction, have been exhibited.

(7) Magnetic or quasi-magnetic effects on common dust have been shown.

(8) Examples have been presented of the remarkable correspondence between some electric figures and living organised forms.

Whether or not my theoretical expositions will hold good, the illustrations I have produced are unimpugnable. They are graphic representations of unseen conditions which demand explanation.

The salient impression which all this leaves on my mind is that electricity is identical with the inherent motion of molecules. There can be no such thing as motionless electricity. The term "statical" only implies bondage and absence of current. The quantity of electrical motion in molecules may be enormous. Faraday has said that there is probably as much electricity in a single drop of water as would produce a thunderstorm if free. I see no reason to dispute it provided we acknowledge all states and conditions of electricity as modes of motion. It may well be doubted whether molecules themselves are anything more than specialised motions. We only recognise them by their forces, and we know of nothing else to represent their substance and their inertia. Lord Kelvin has shown convincingly that rigidity and elasticity, which carry with them the ideas of solidity and inertia, together with oscillation in all its forms, can be represented by motion. No man can speak with higher authority on this subject than he can, and he has said, "It is scarcely possible to help anticipating the arrival of a complete theory of matter in which all its properties will be seen to be merely attributes of motion." But motion of what? At present we assume the existence of ether to supply the supposed need of a subject, and also to fill up gaps in continuity. But is it easier to conceive a continuity of ether than a continuity of inter-acting motions? I confess my inability to judge, but we are more familiar with motion than with ether, and we do not seem to gain much by postulating two inscrutables instead of one. The elimination of motion would in the one case mean the extinction of the universe; while in the other, there would only remain an impalpable medium, which in the absence of motion would be scarcely distinguishable from empty space. Endow space with the attributes assigned to ether, and the difference vanishes. Motion would then stand forth as the "absolute" of matter. But much the same may be said of it, even if the independent existence of ether be conceded.

These views of the structural capacity of motion present Nature under a more spiritual aspect than one of crude Materialism; and while they lead us to contemplate her wonders with increased amazement, they make her appear more akin to an Infinite Dominant Mind.

Before concluding my remarks, I must apologise for the scant reference I have made to the important labours of modern investigators in the field of electricity. Age and business avocations have imposed upon me the necessity of being as brief as possible in the treatment of my subject; and my inability to follow the elaborate mathematical treatment now so generally adopted in electrical exposition unfits me for acting as a reviewer. I freely admit that my own investigations are built upon pre-existing knowledge, and I hope they will not clash with those of others. Personal claims to priority are most distasteful to me; and if I have in any case treated as new what was known before, I hope it will be attributed to ignorance and not to intention.

It yet remains for me to acknowledge the valuable services which have been rendered to me in the prosecution of my experiments by two persons. The one is Mr. WORSNOP, a well-known photographer in Rothbury, and the other is Mr. ANDREW RICHARDSON, who has acted as my general assistant. Both have displayed great intelligence and fertility of resource when acting under novel conditions.

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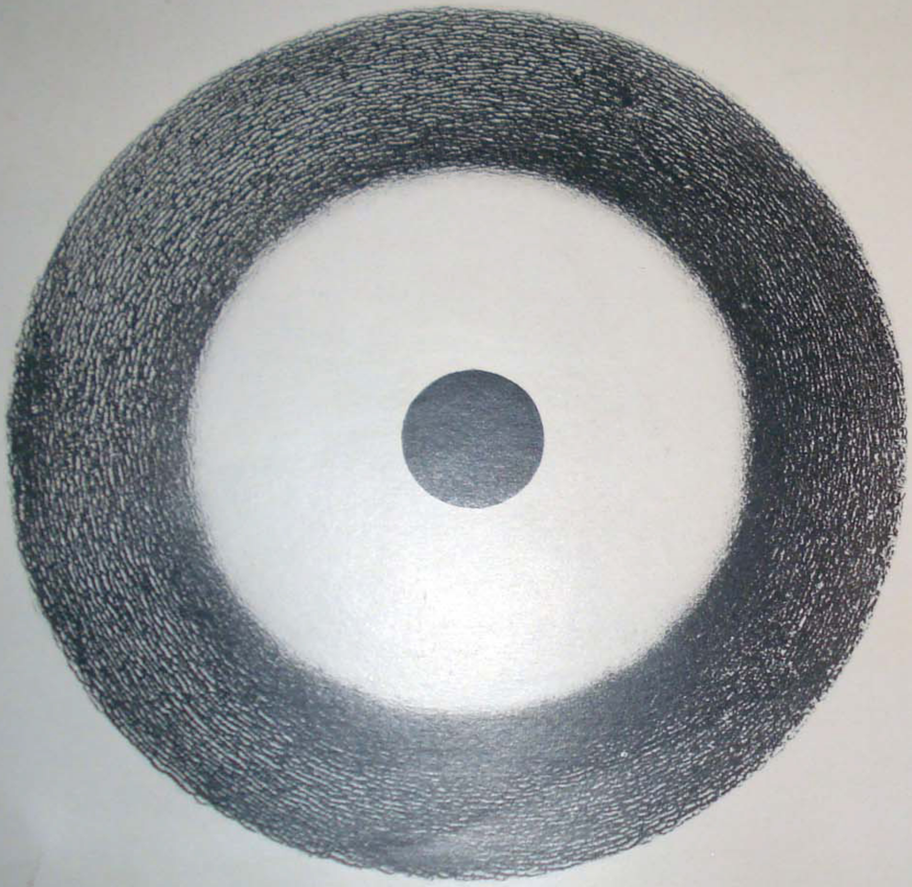

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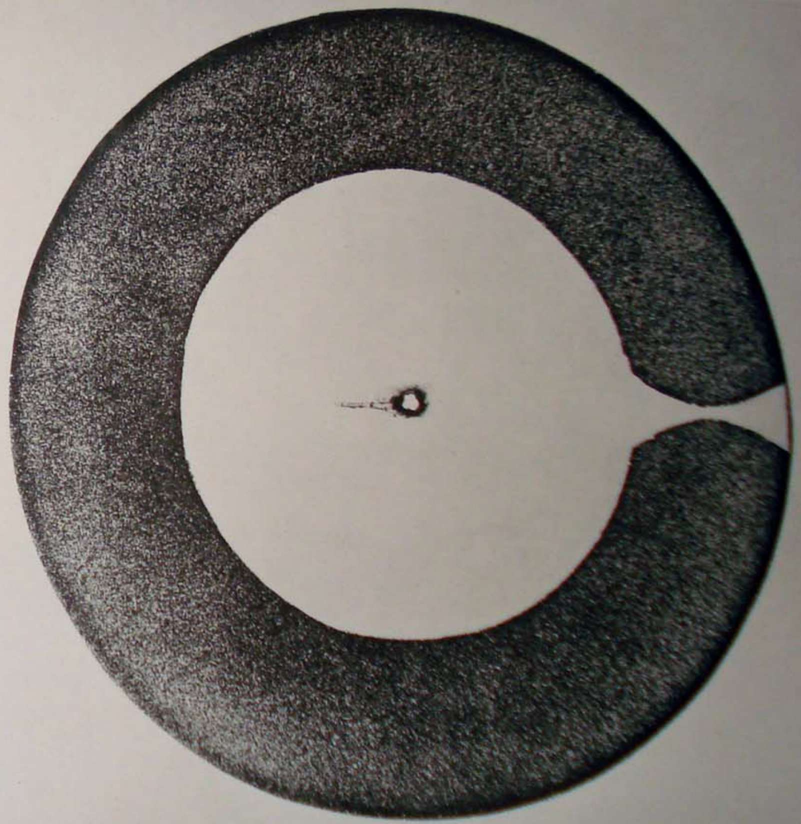

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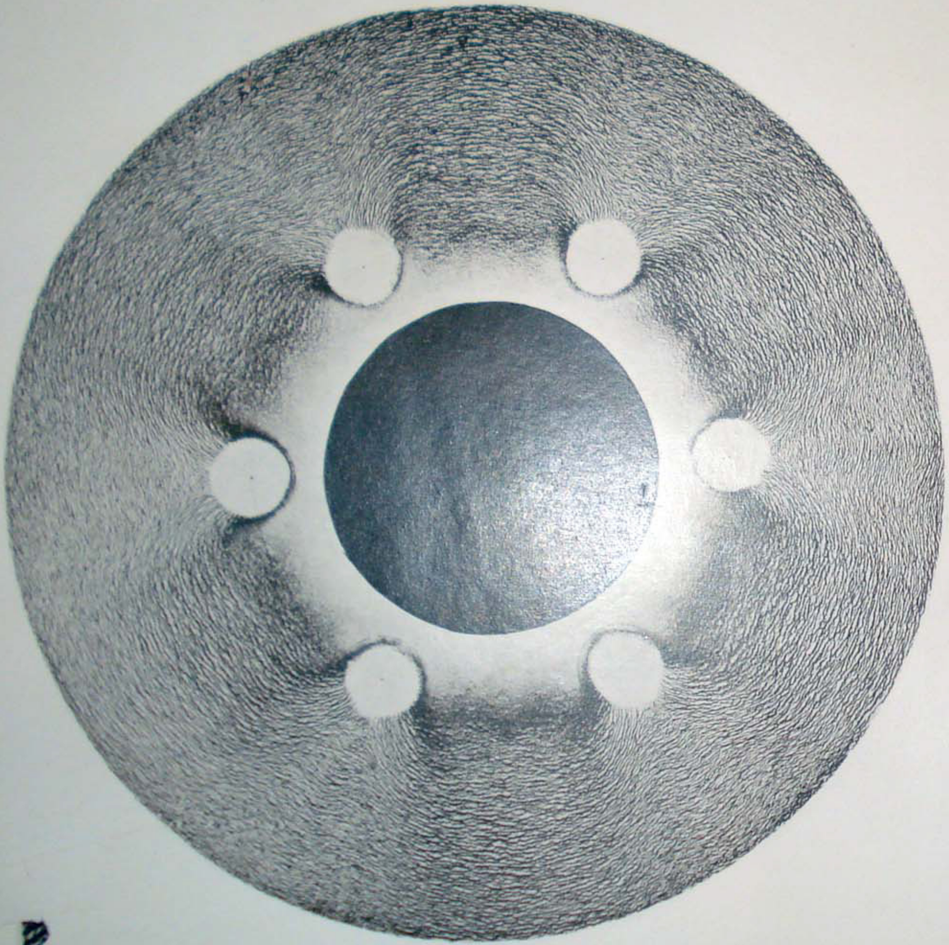

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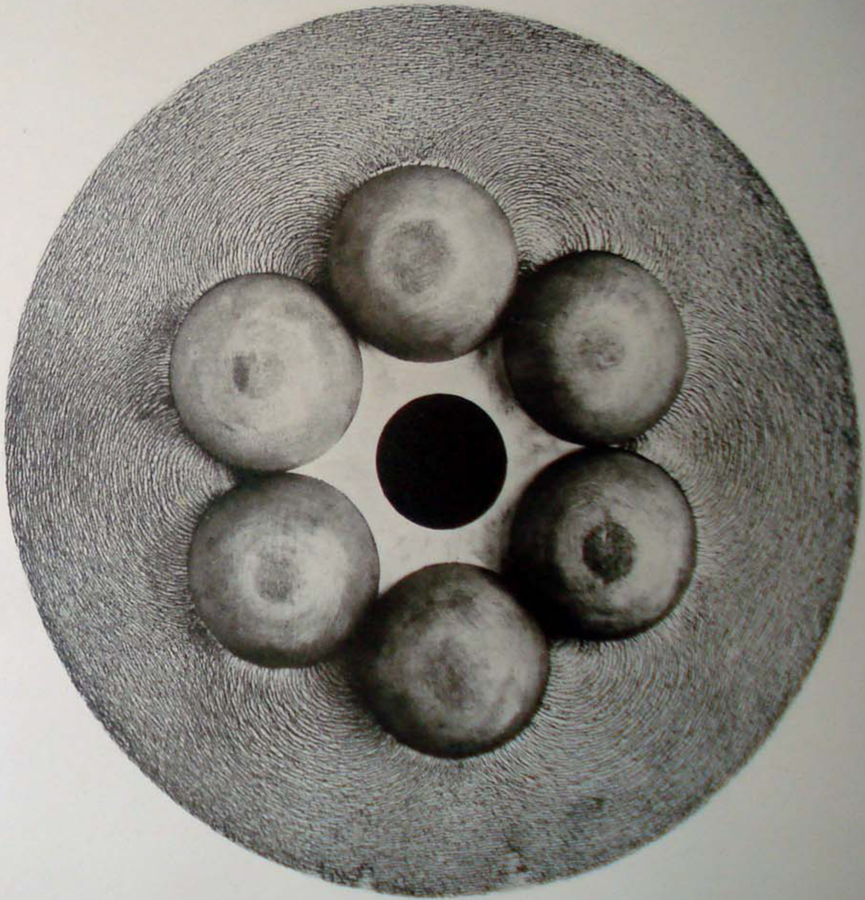

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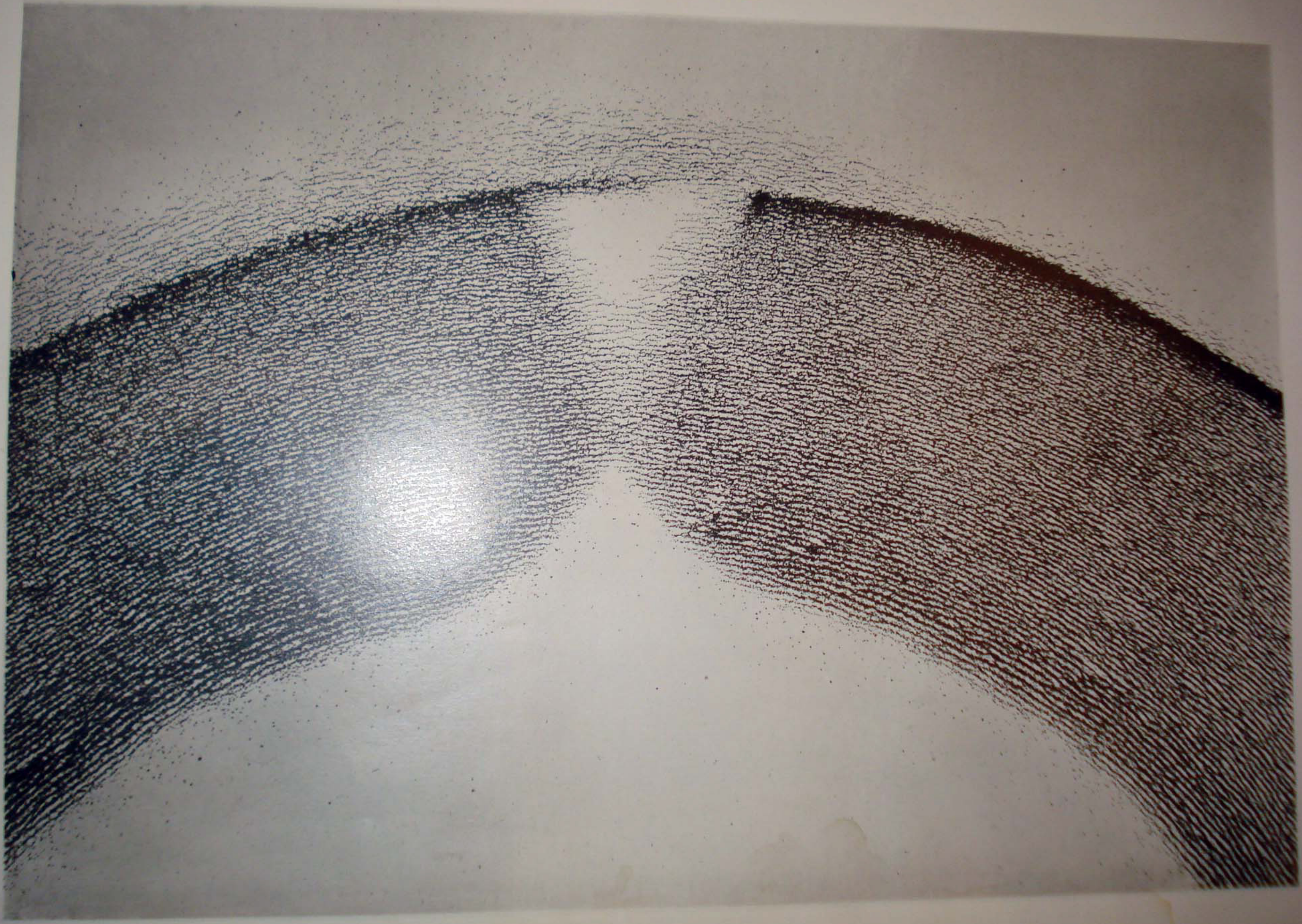
TWICE ORIGINAL SIZE.



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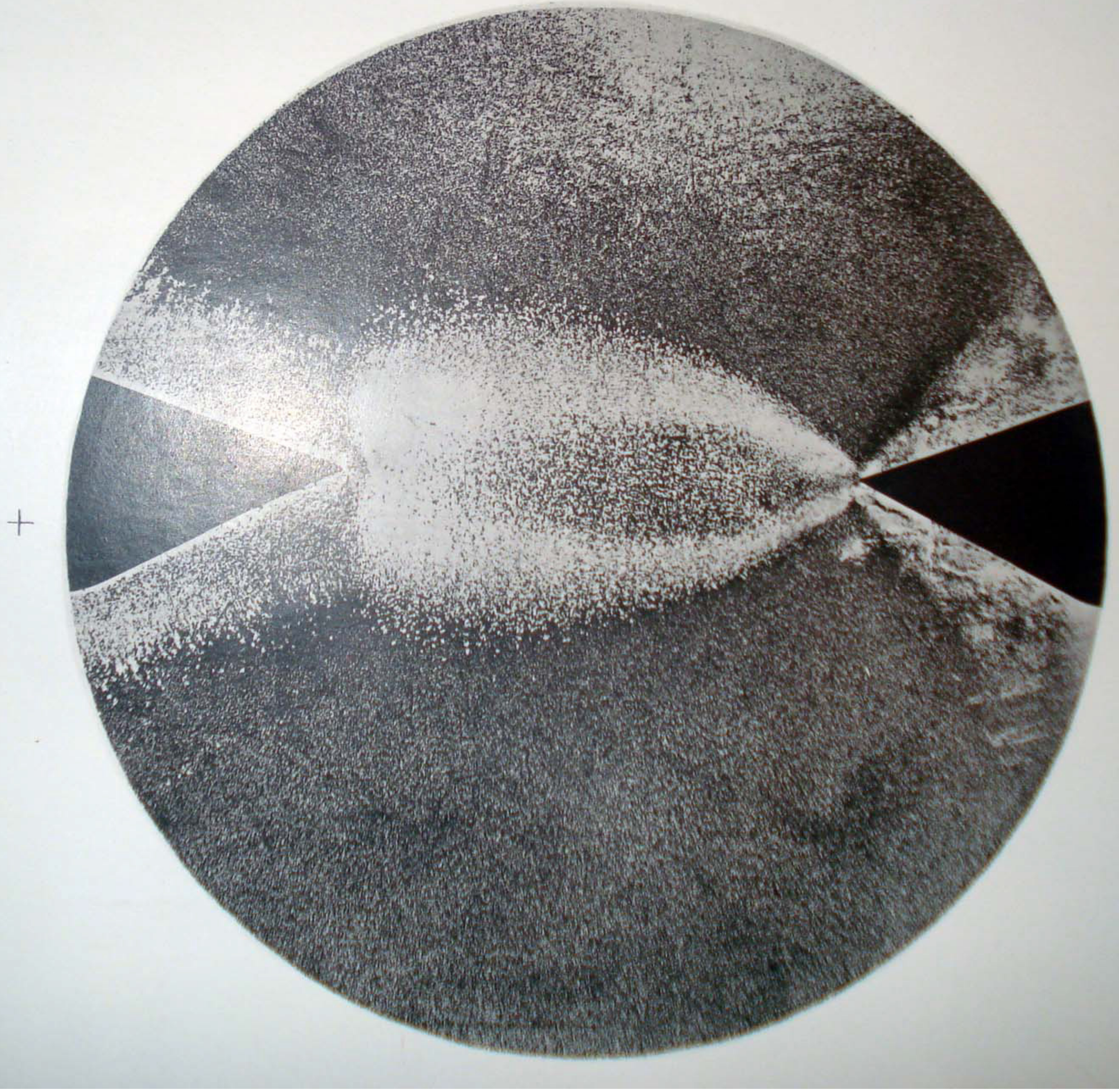

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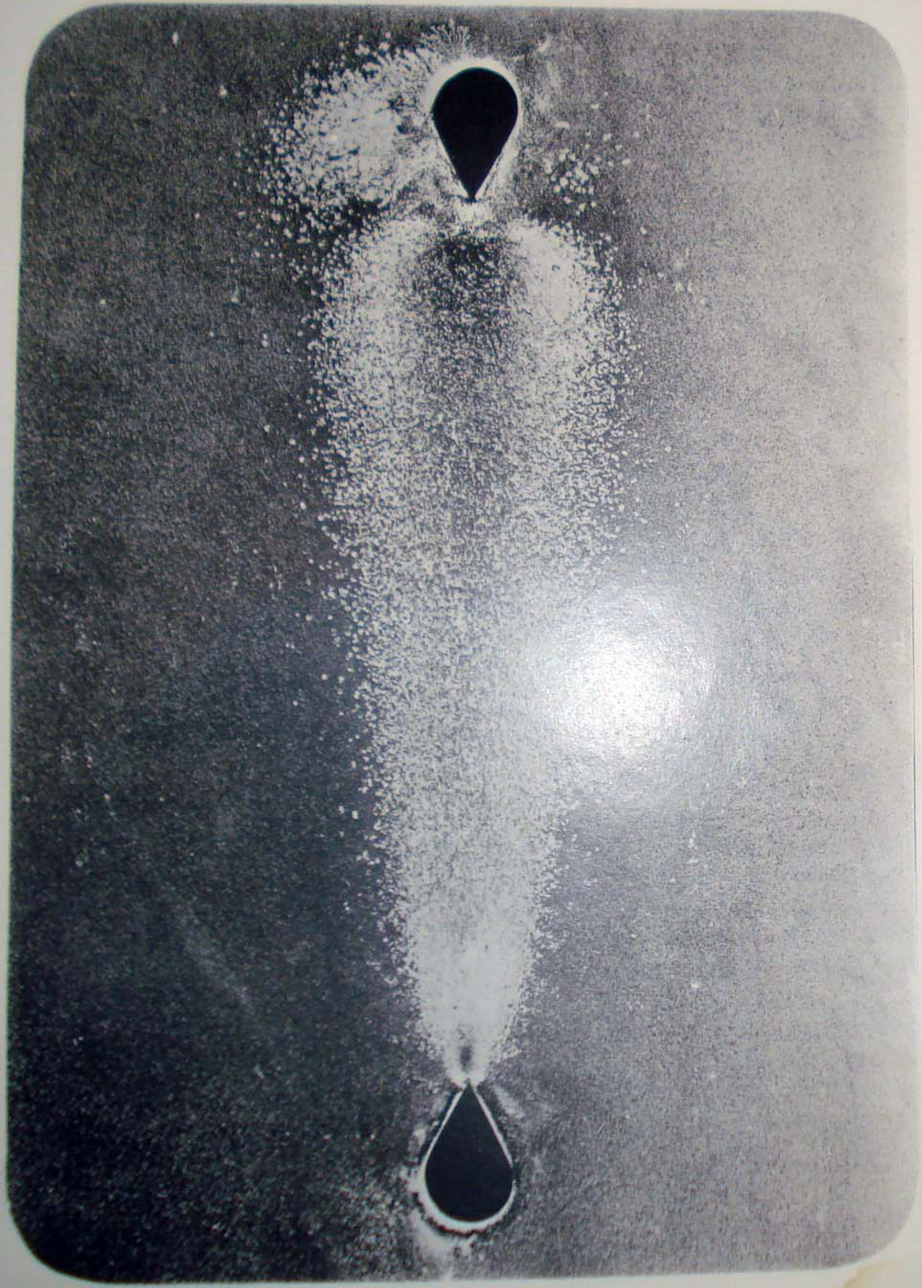

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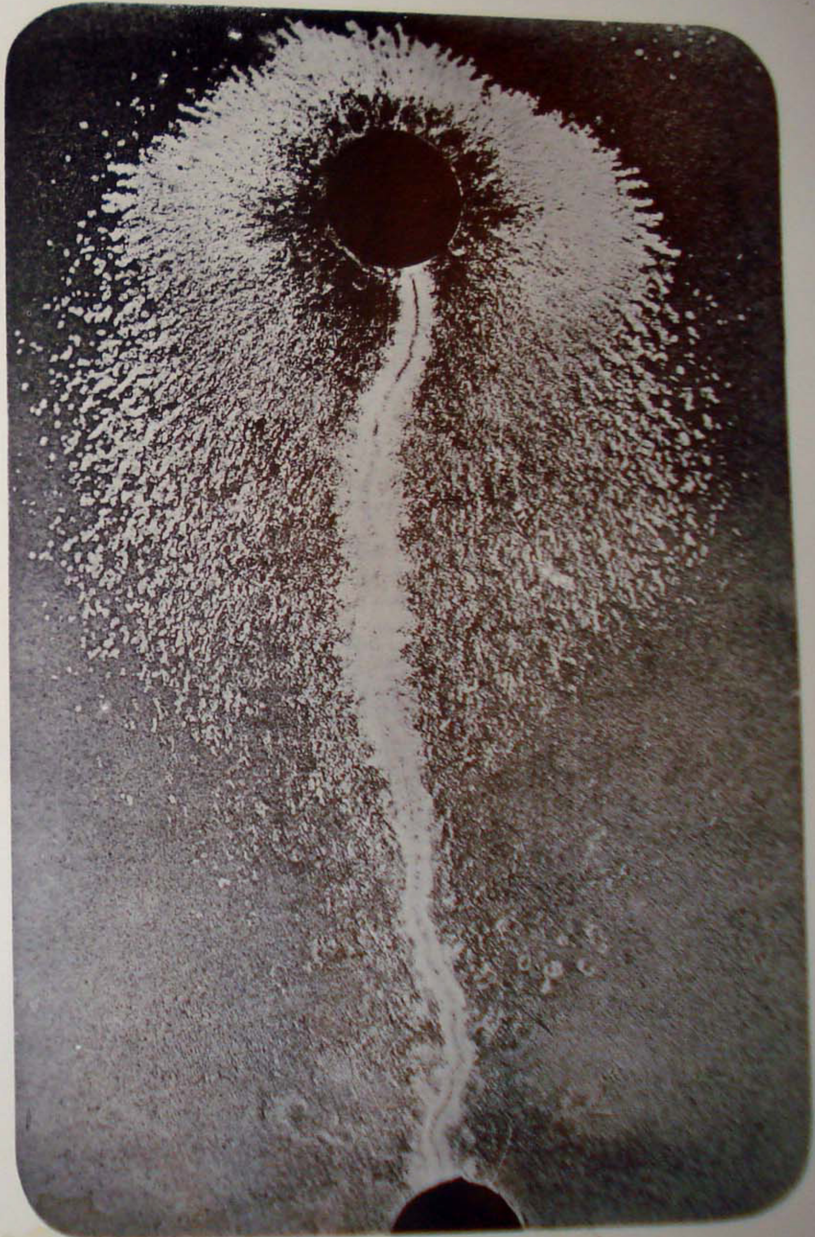
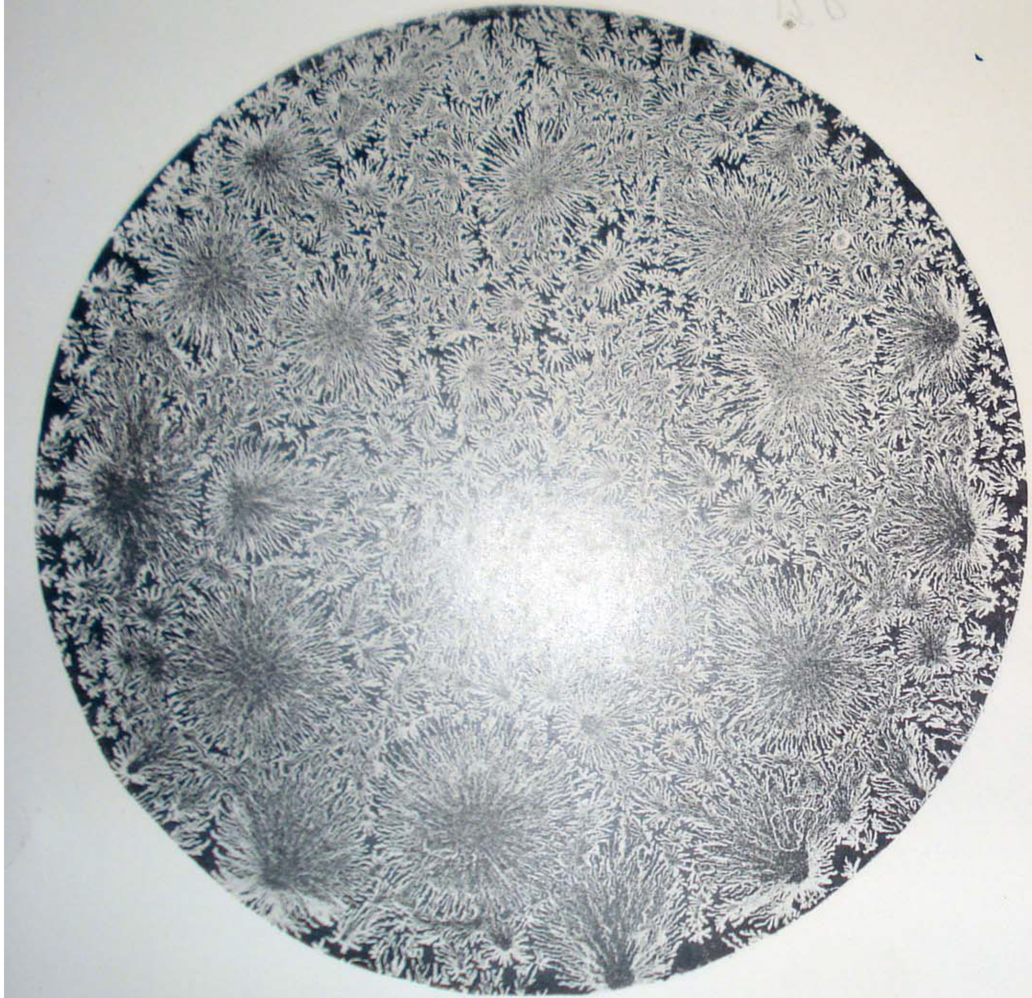


No. 9.

POSITIVE FIGS.



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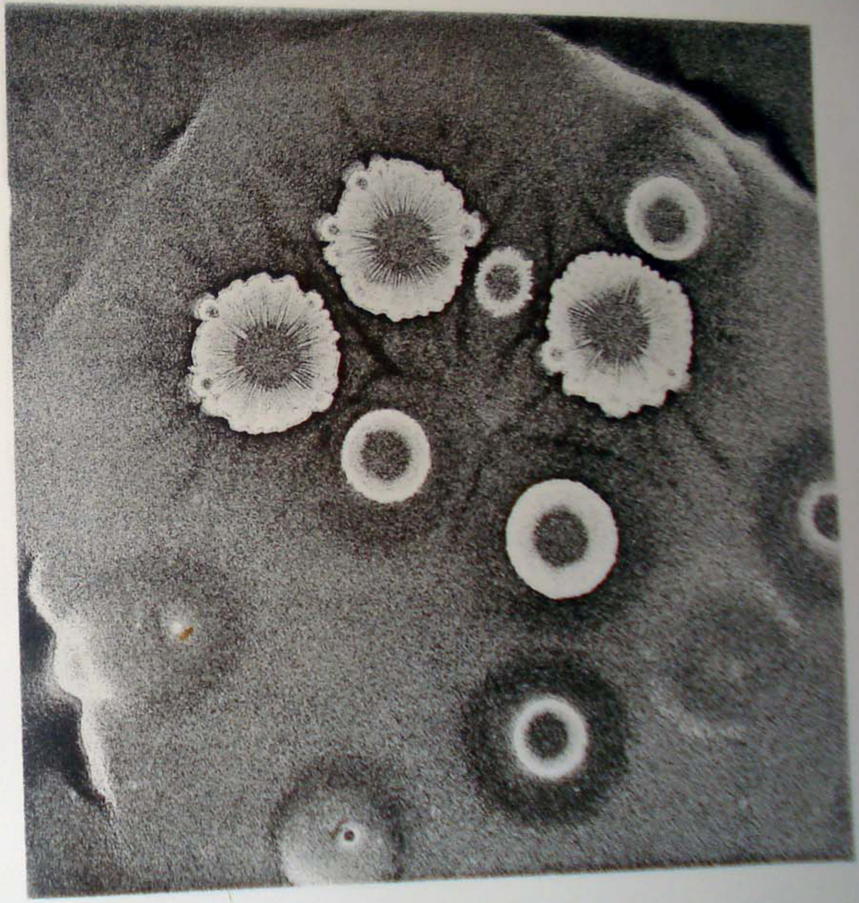
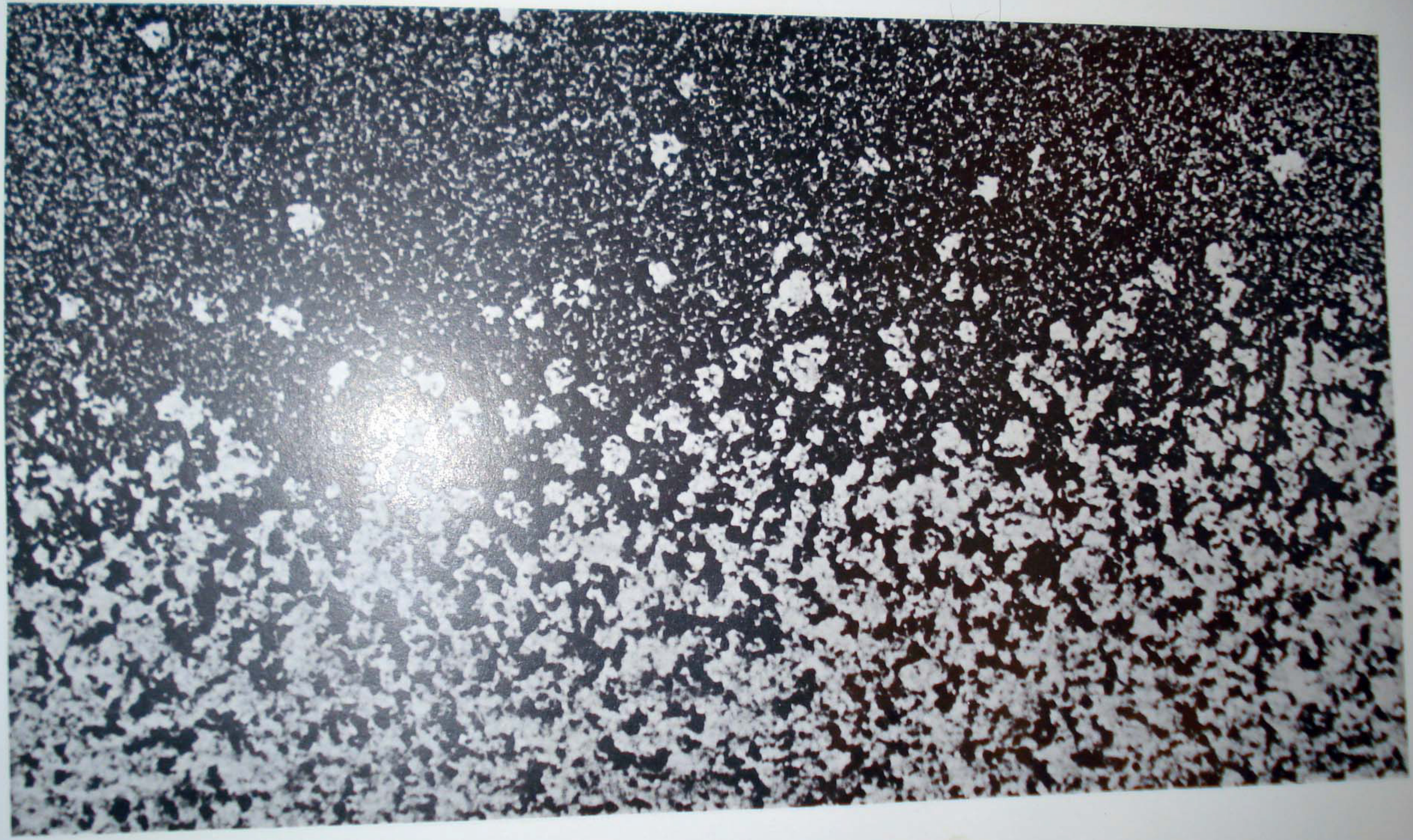
NEGATIVE FIGS.



No. 11.

GREATLY ENLARGED.



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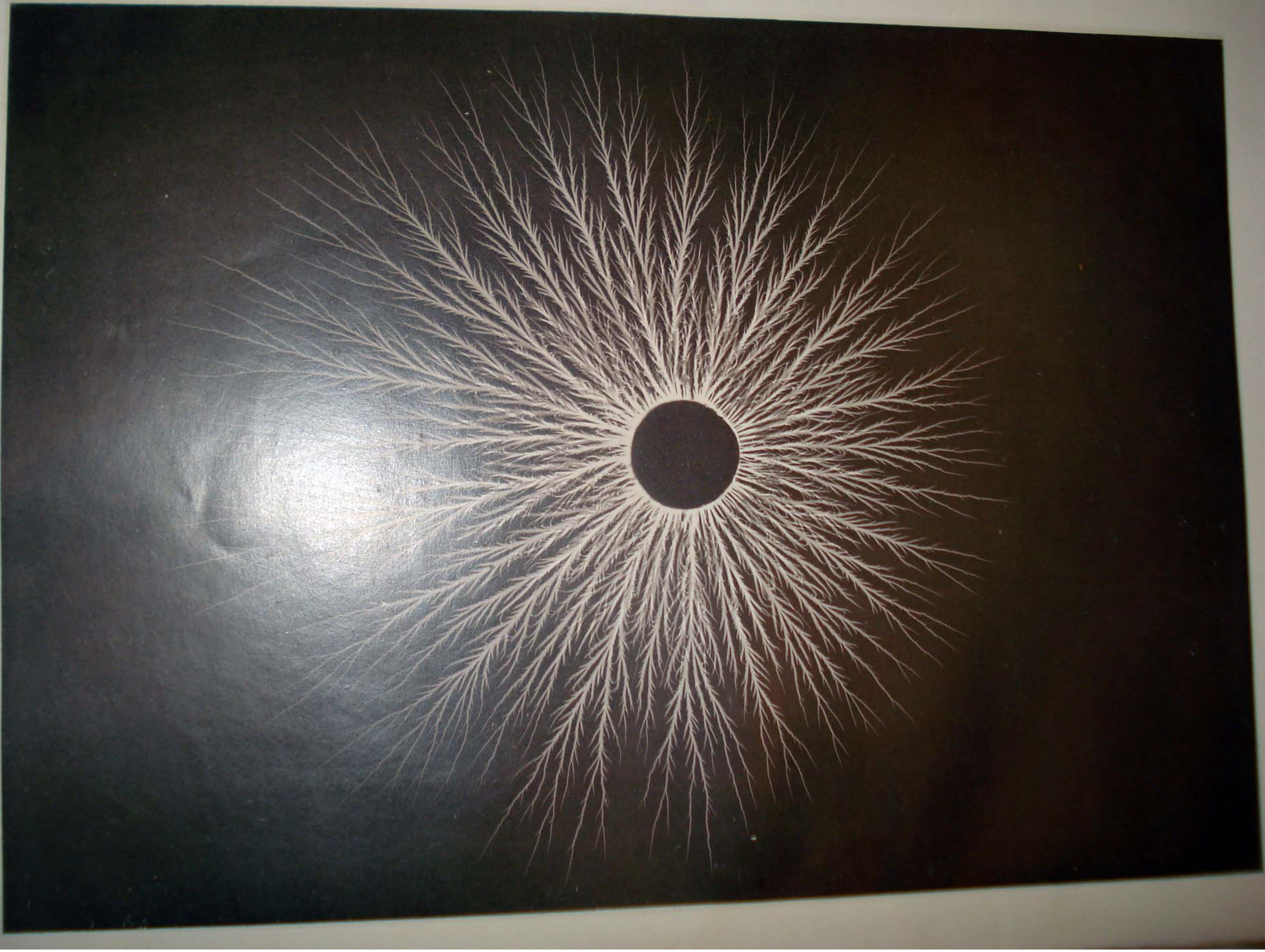

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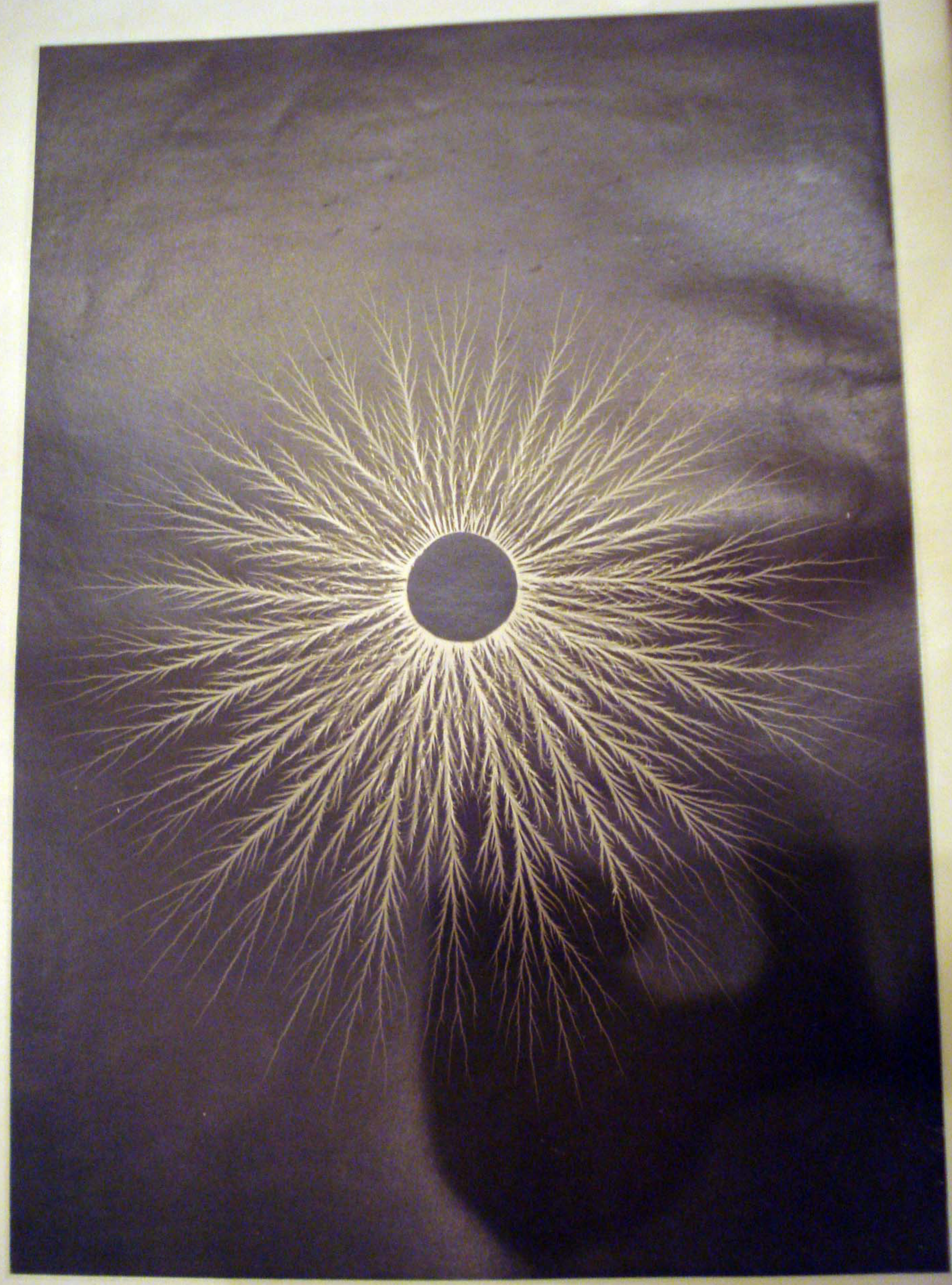

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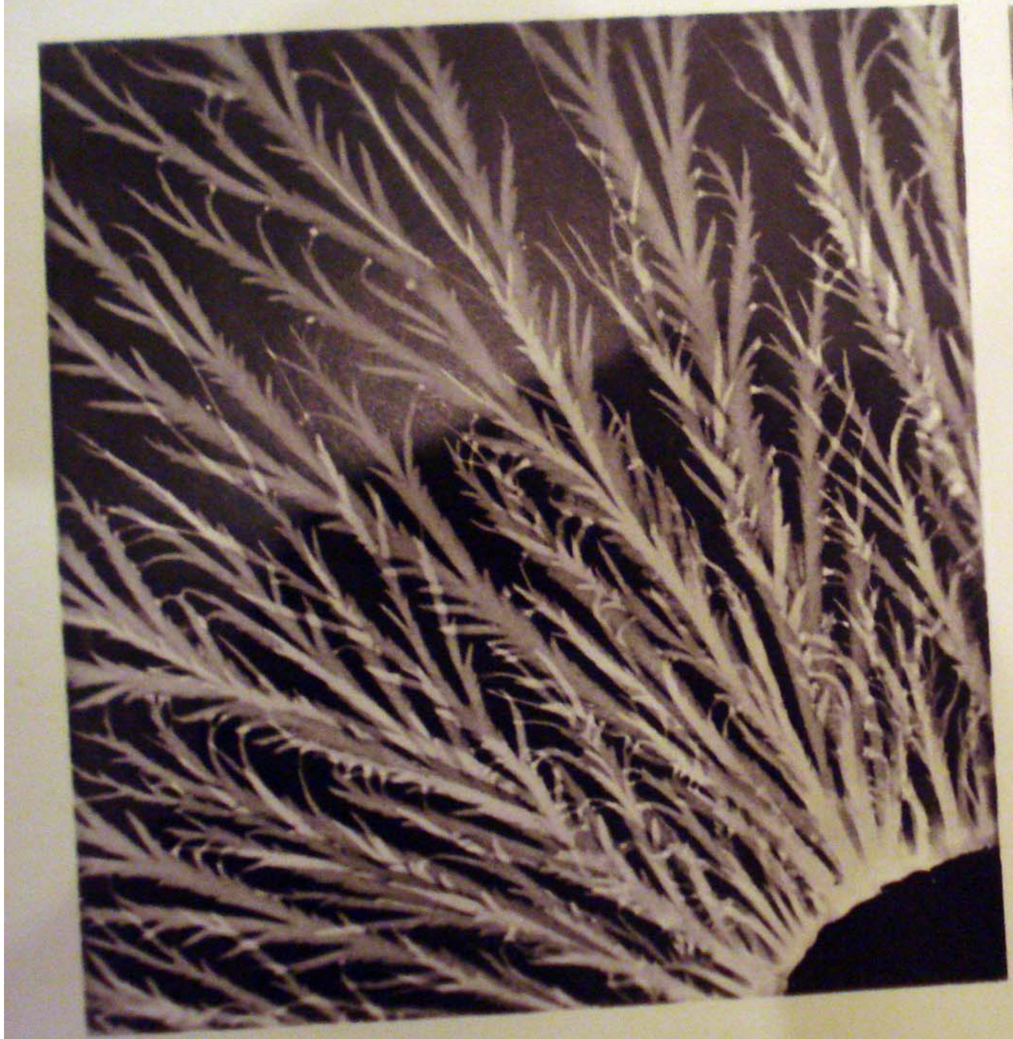

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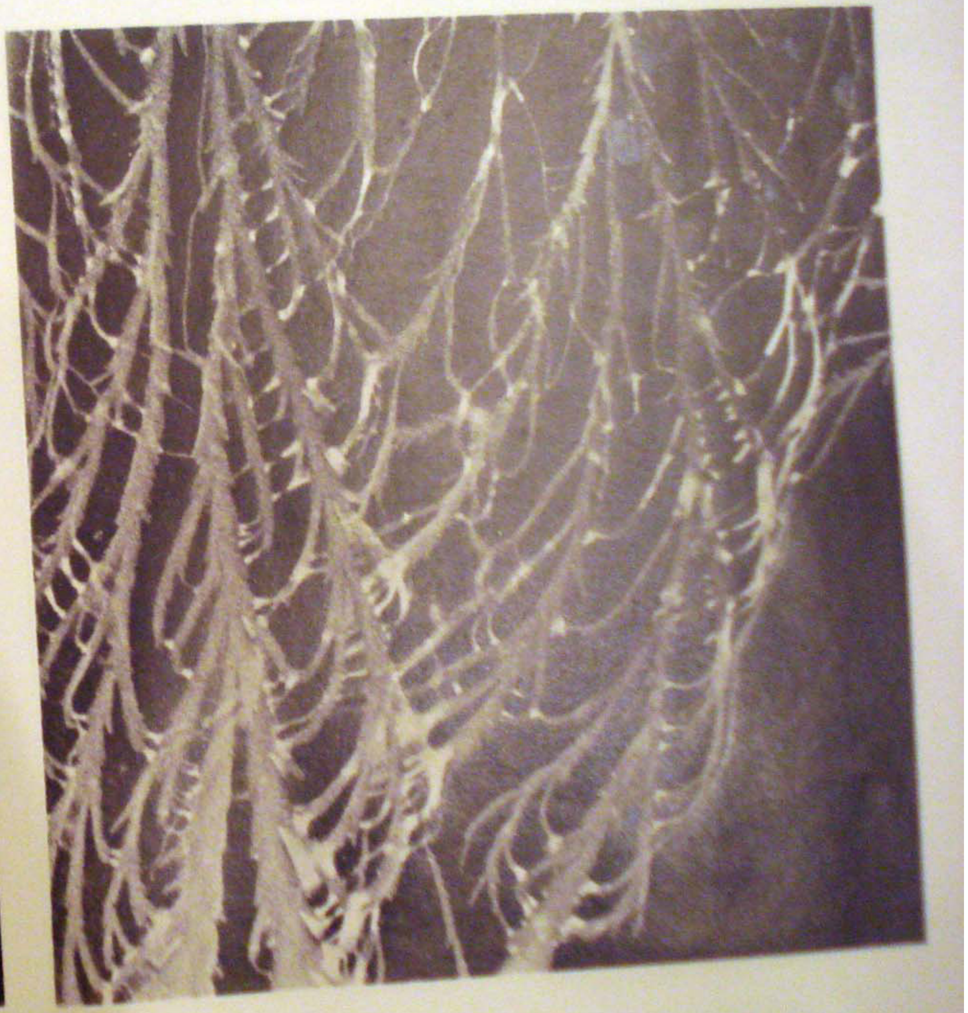

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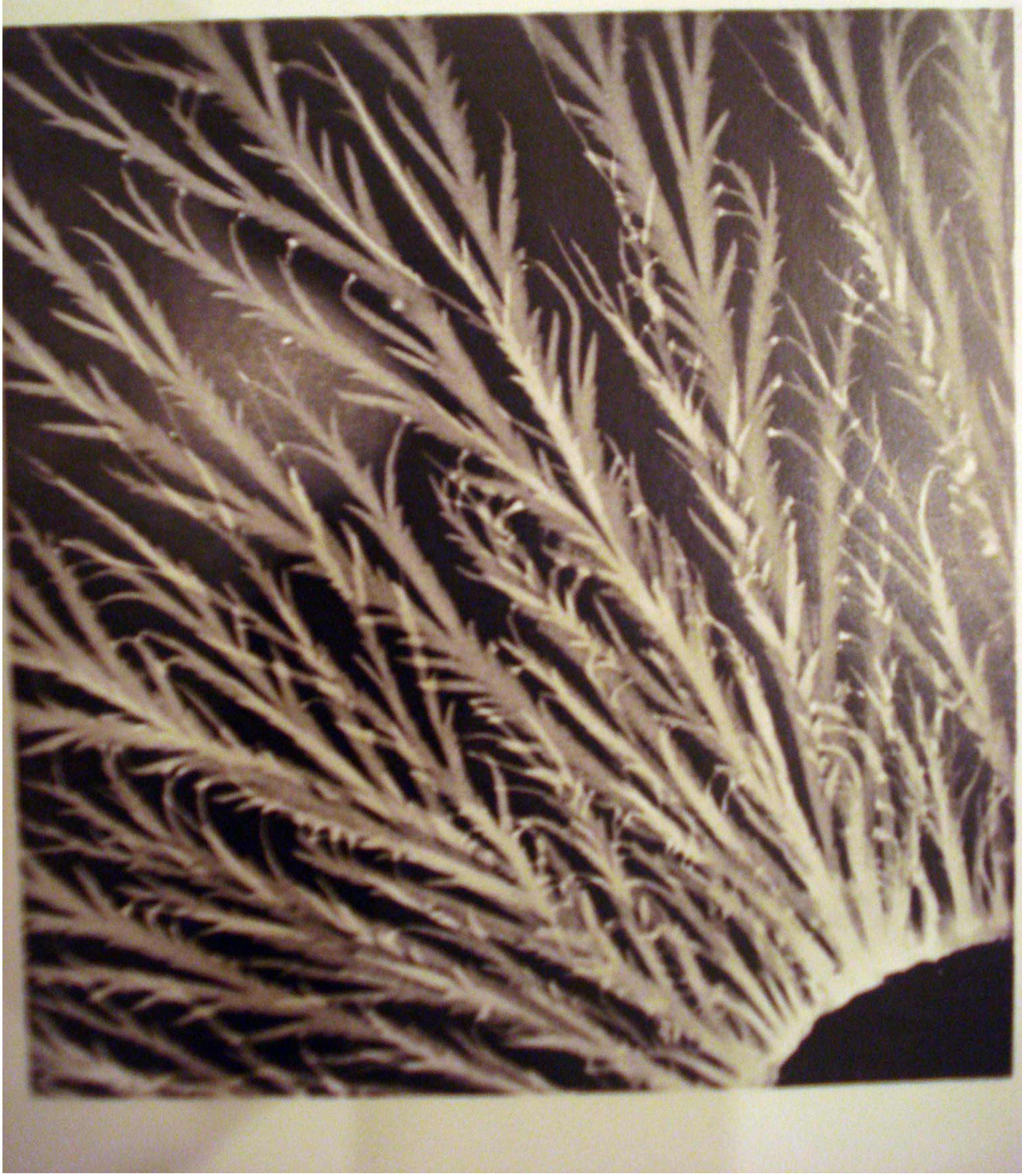

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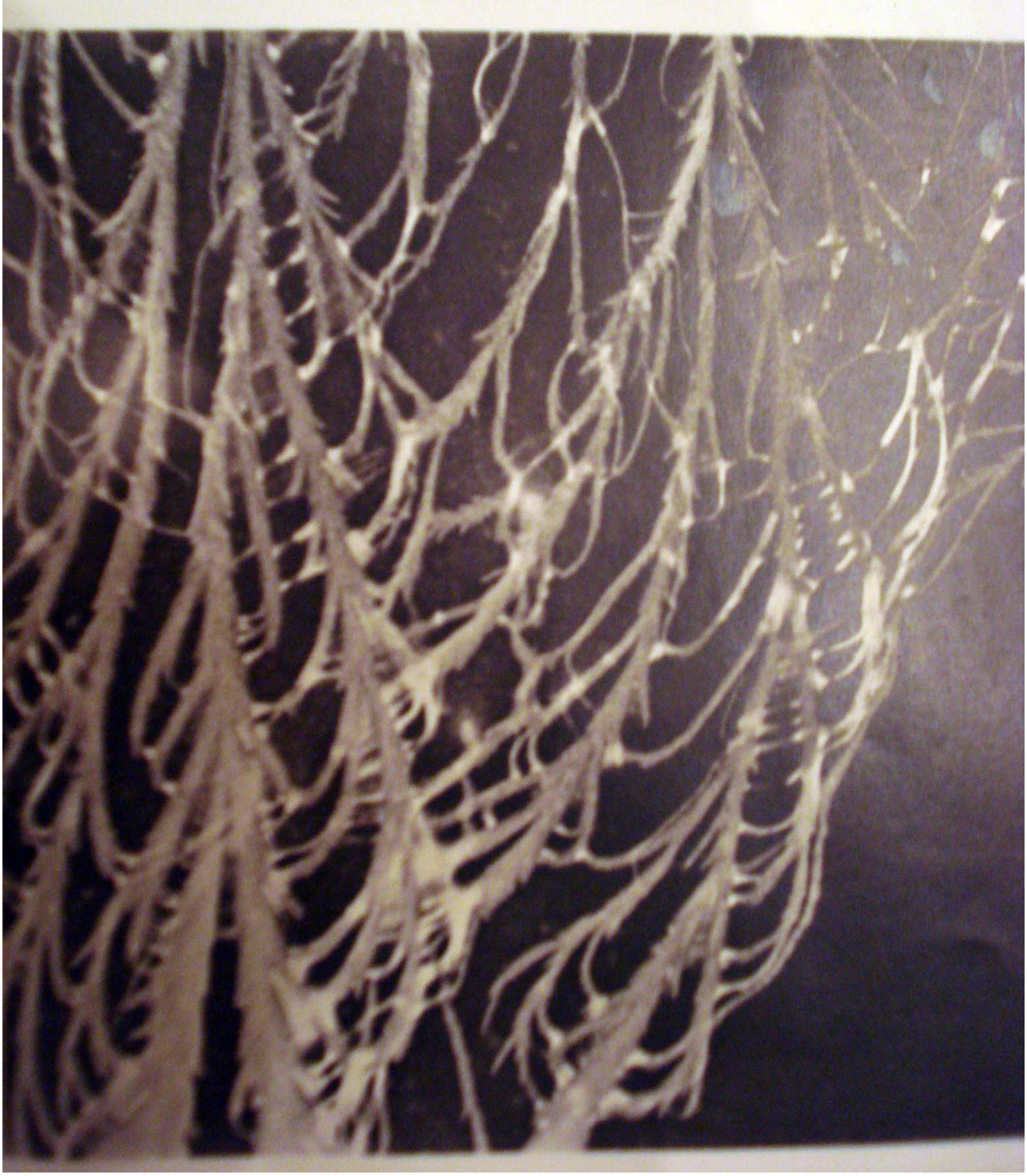

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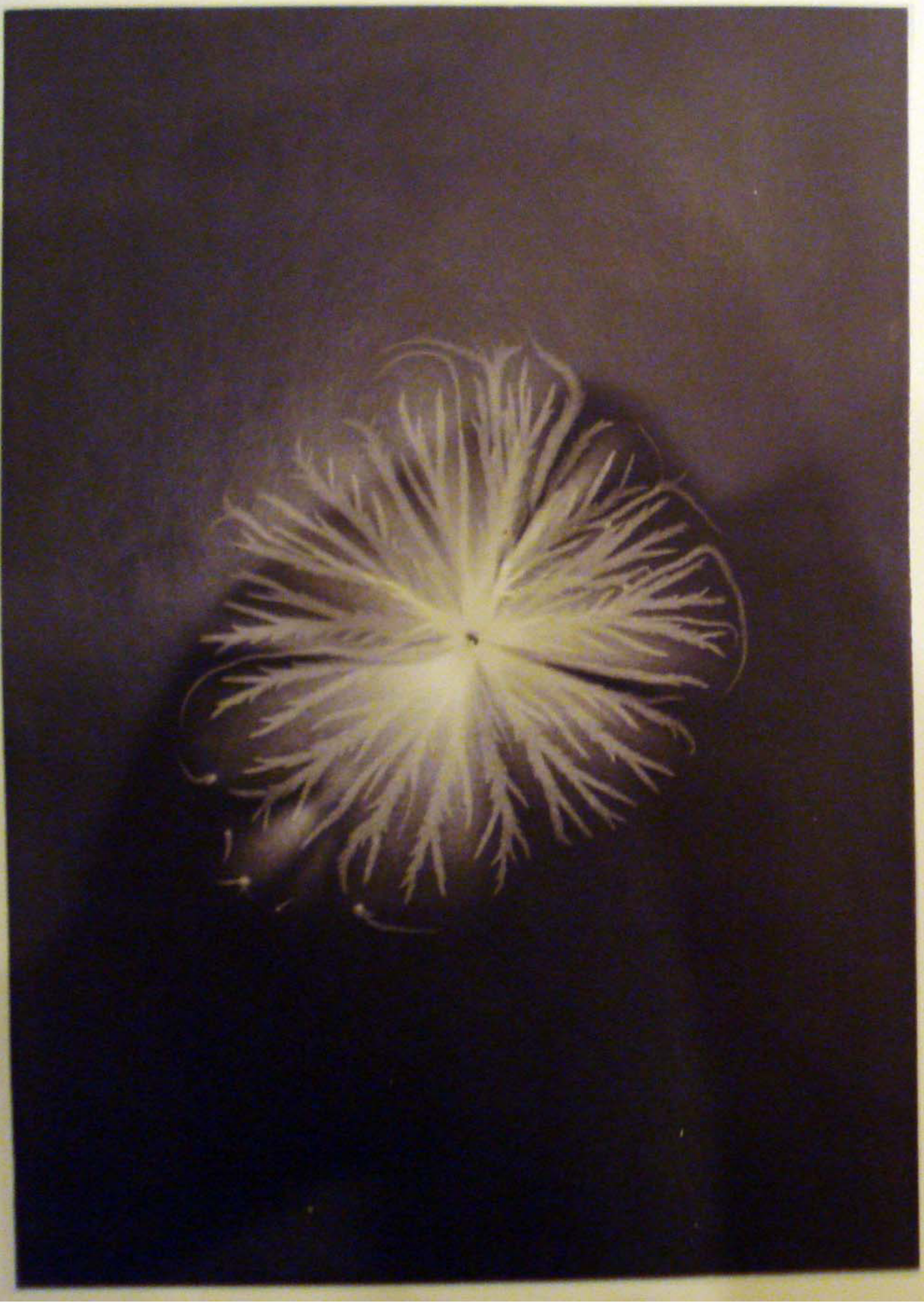

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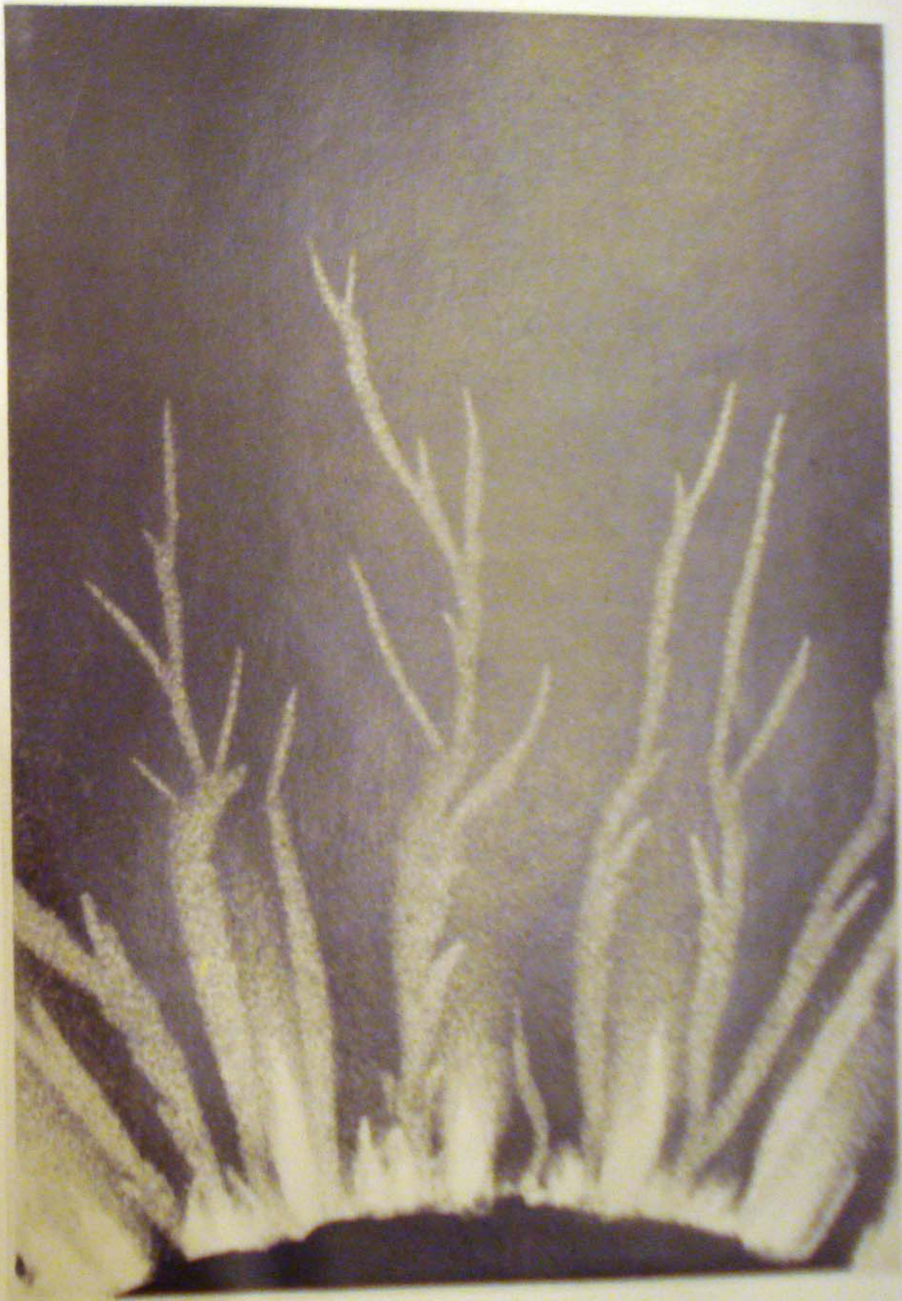

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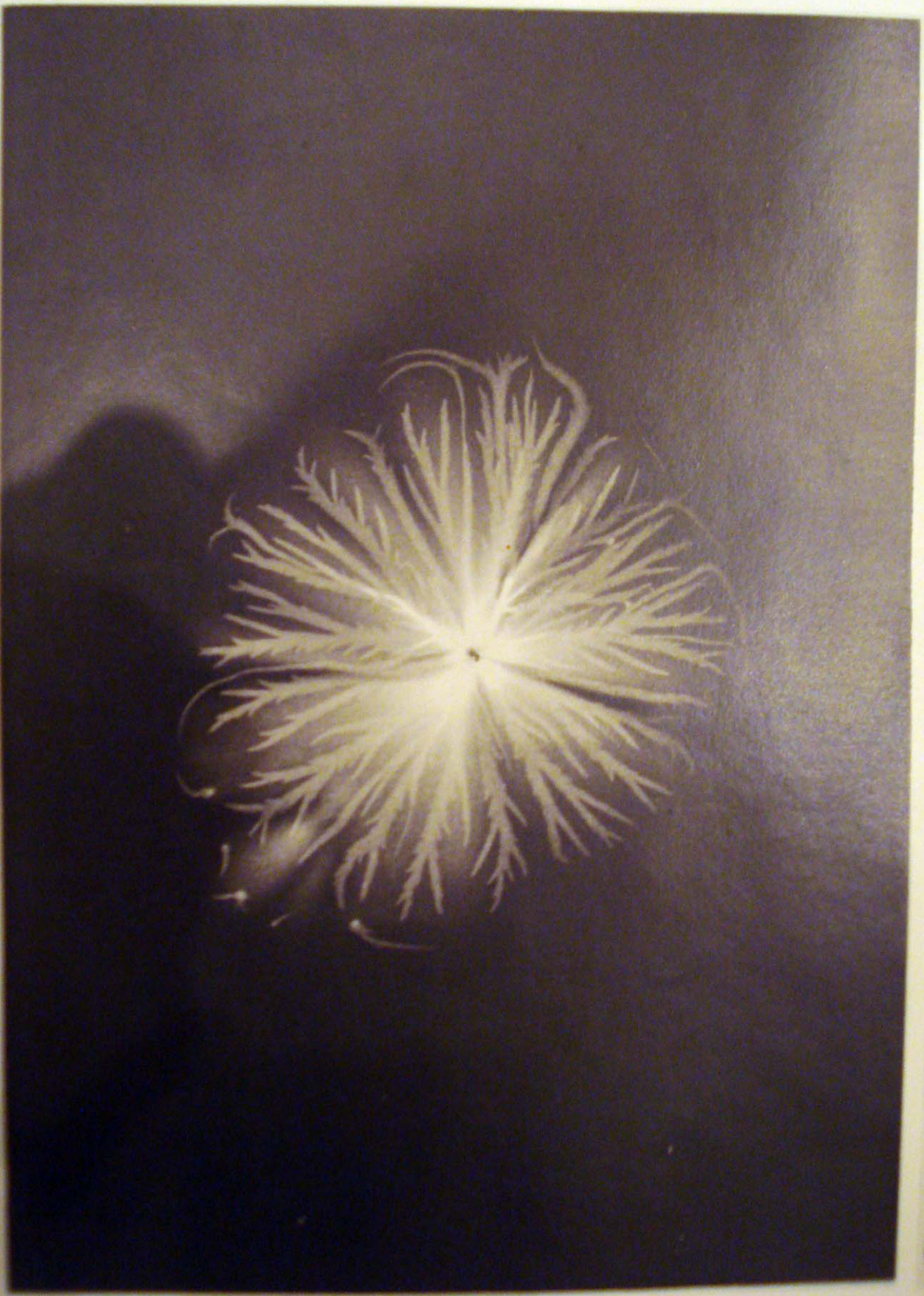

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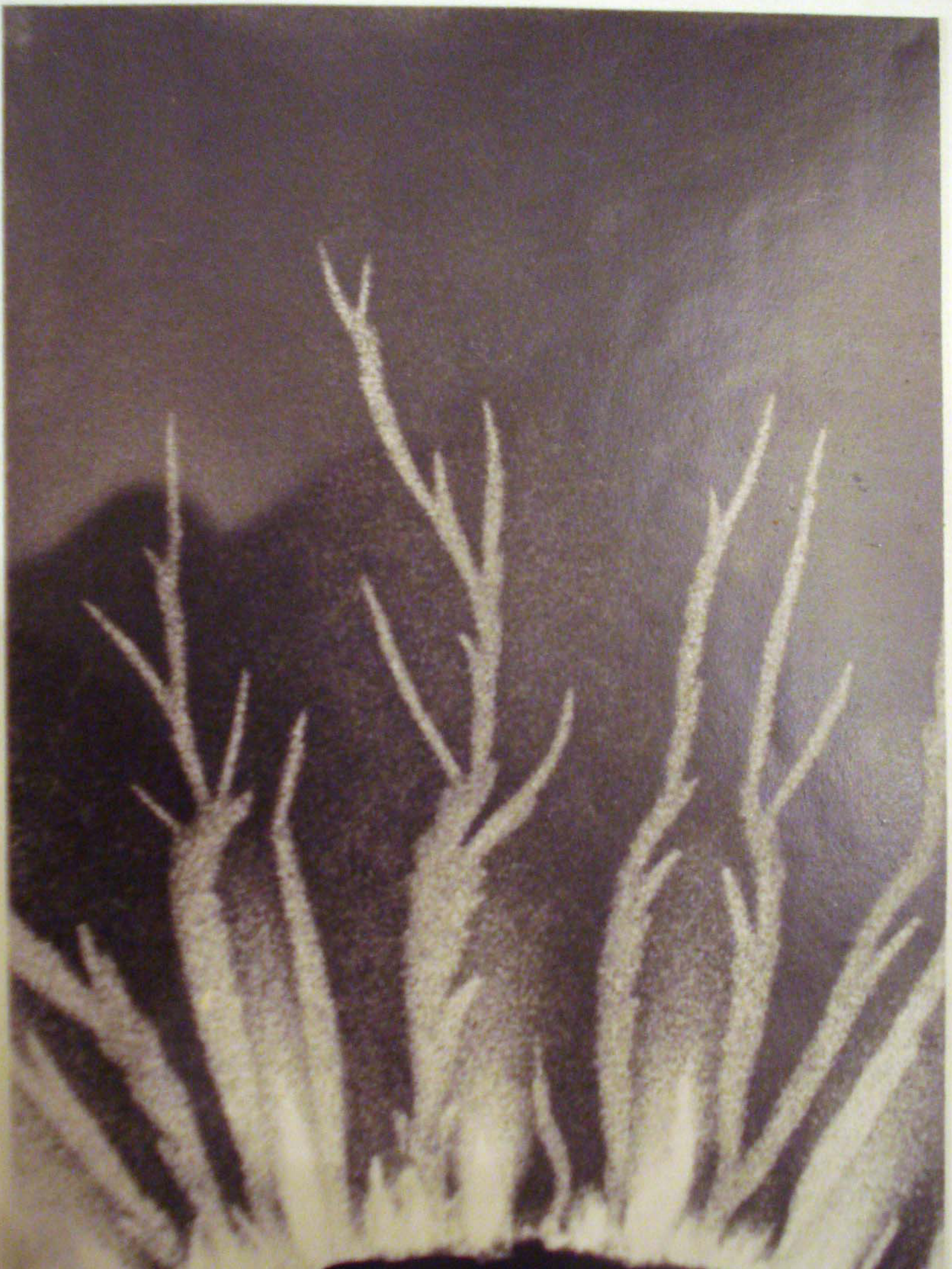

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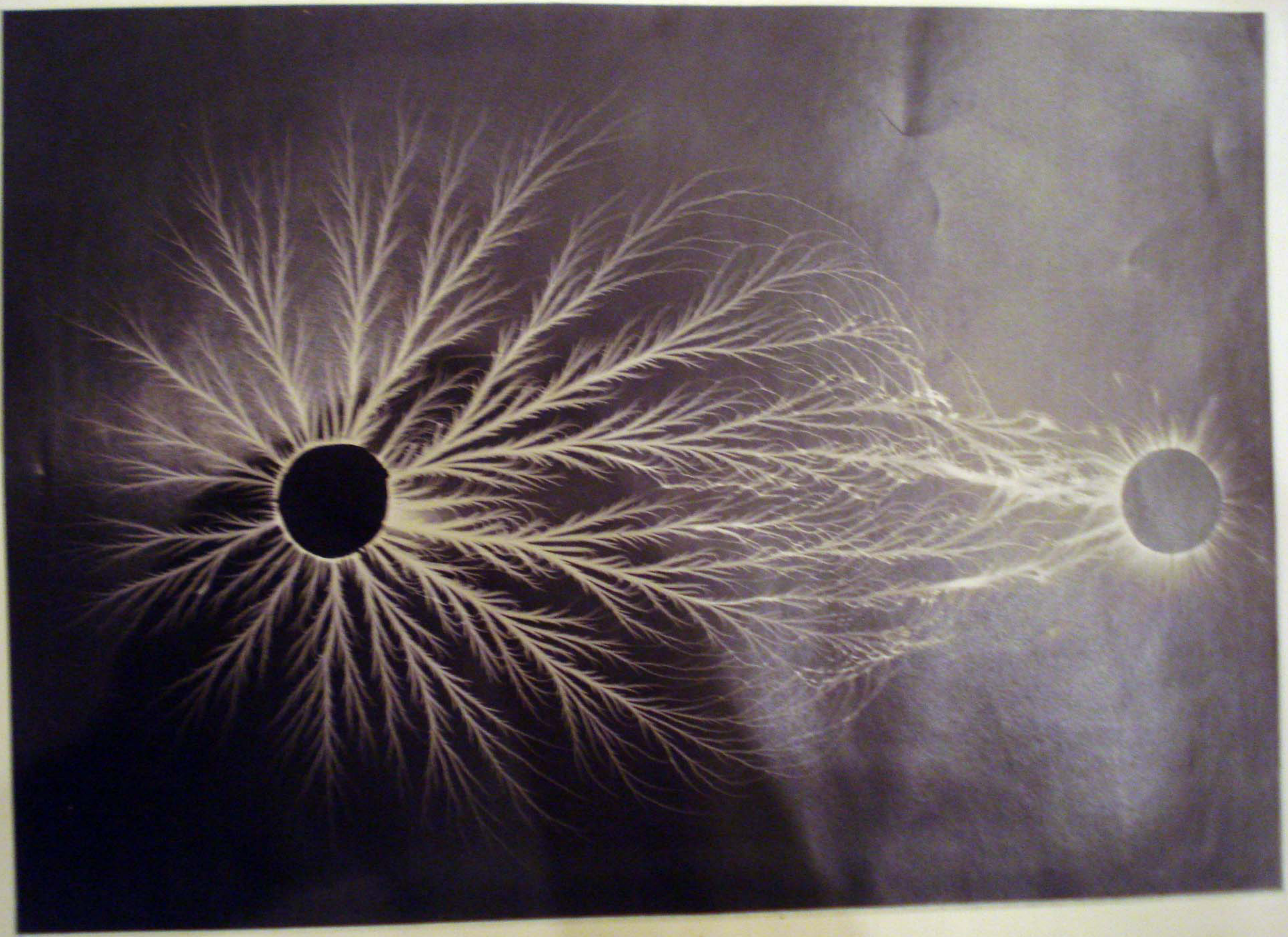

No. 18.